Time-sharing efficiency in children and adults validation of a developmental model of divided attention.

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TIME-SHARING EFFICIENCY IN CHILDREN AND ADULTS:

VALIDATION OF A DEVELOPMENTAL MODEL OF

DIVIDED ATTENTION

by

© Ruth Anne Carter

M.A. University of Windsor, 1984
B.A. Saint Mary's University, 1981

A Dissertation
Submitted to the Faculty of Graduate Studies
through the Department of Psychology
in Partial Fulfillment of the
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Abstract

This study evaluates the ability of the multiple-resources model of attention (Navon & Gopher, 1979; Wickens, 1984) to describe and explain cognitive developmental change. The multiple-resources model states that attention is one type of resource within the human information processing system, and this resource is both distributable and in limited supply. Support for the multiple-resources model has been found in research studies requiring adult subjects to divide their attention between two concurrently presented tasks under varying instructions for task emphasis. However, very few comparable studies have been conducted using child subjects, and methodological limitations within these studies prevent conclusions regarding the accuracy of the model for explaining cognitive development in childhood. In the present study, the divided attention paradigm is used to assess the validity of the model from a developmental perspective.

Twelve subjects within each of grades 2, 5, and 8, and twelve university students were required to respond to two concurrently presented memory tasks under varying payoffs for accurate performance. The two memory tasks differed on
input and output modality (i.e., visual-manual and auditory-vocal). Task difficulty was established on an individual basis according to a criterion performance level. An easier and a more difficult version of each task was presented to the subjects under varying payoff conditions in a counterbalanced order. The design of the study was a mixed factorial combination of Grade (4 levels), Auditory Task Difficulty (2 levels), Visual Task Difficulty (2 levels), and Payoff (3 levels). All factors except Grade were manipulated within-subjects. A diagram-balanced Latin-square was used to counterbalance the order of the 12 within-subject conditions.

The results indicated developmental consistencies in some aspects of information processing when knowledge base differences and memory span are controlled. These consistencies were reflected in the cost of concurrence which was developmentally stable. However, developmental inconsistencies were obtained in relation to voluntary control over the allocation of attention to a higher priority task. These data provide general support for the multiple-resources conceptualization of attention. However, the results also address the need for developmental research to explain the changing nature of the processing system. Directions for future research and educational implications are discussed.
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CHAPTER I
INTRODUCTION

The human information processing system places limitations upon the individual's ability to accurately receive and respond to two concurrently delivered messages. A common phenomenological experience that supports the contention of limitations on processing is the difficulty one experiences in attempting to attend to two or more conversations simultaneously. The research which addresses the limiting factors within the processing system has led to the development of numerous models of attention (Broadbent, 1958; Treisman, 1963; Deutsch & Deutsch, 1963; Norman, 1968; Norman & Bobrow, 1975, Navon & Gopher, 1979; Wickens, 1984). Most of the supportive research for models of attention has drawn its subjects exclusively from the adult population. To date, no comparable developmental models of attention have been proposed.

Developmental models attempt to describe and explain age-related changes in behavior (Miller, 1983). A valid developmental model of attention must be able to accommodate and explain developmental changes in the efficiency of cognitive processing. The present research endeavor is
proposed as a step toward establishing a developmentally
valid model that describes the role of attention in the
human information processing system. The proposed study
will address the need for an encompassing theoretical
framework which describes the observed consistencies in
information processing in children and adults, as well as
the inconsistencies resulting from several exclusively
developmental limitations on processing.

This chapter reviews the literature on attention. The
first section of this review is devoted to models of
attention. Within this section, the early theoretical
formulations of attention are presented in order to
establish a context for more recent theoretical postulates.
The model which is most parsimonious with the research
findings on adults is delineated in detail. The second
section of this review is devoted to the developmental
literature on attention. Several specific developmental
limitations on information processing are described. The
final section of this chapter is devoted to the development
of a controlled study to assess the applicability of the
outlined model for explaining attention in children.
Defining Attention

Foremost, attention is a phenomenological experience common to all humans. It is this experience of attention that William James (1890) referred to when he stated that "everyone knows what attention is" (p. 403). However, the phenomenon of attention does not readily lend itself to scientifically rigorous definition.

The concept of attention, as it is used in Information Processing Theory, is an abstraction which has meaning only to the extent that it allows researchers to refer to a commonly observed set of experimental findings. Solso (1979) defined attention as the concentration of mental effort on sensory or mental tasks and related it to four areas of research: (1) processing capacity and selective attention, (2) level of arousal, (3) control of attention, and (4) consciousness.

Attention is defined in cognitive research as that aspect of our information processing system that allows us: (1) to selectively choose information from the stimulus field for further processing (Duncan, 1985; Broadbent, 1970; Enns & Gierzus, 1985; Solso, 1979), (2) to consciously focus on one aspect/channel/portion of the stimulus field and ignore simultaneous input distractions (Enns & Gierzus, 1985; Enns & Cameron, 1987), (3) to divide effort/energy/resources
between two simultaneous inputs when this is the goal and furthermore to manipulate output (payoffs) by manipulating the division of resources (Navon & Gopher, 1979; Wickens, 1984), and (4) to sustain or maintain focused effort/energy/resources on a particular task when this is the goal (Parasuraman, 1984).

Attention may be considered a resource of the system in that it is available to be drawn upon when the system requires it. Attentional resources allow the human processor to select input, maintain items in an active state in memory, focus or divide attention at will, and sustain a set performance level on tasks over long durations. This conceptualization refers to a functional definition of attention.

**Resource Theory**

Navon (1985) defines 5 properties of attentional resources that are central to resource theory: (1) resources come in units which are distributable, (2) a single resource unit can be used by only one process at a time, (3) different resources can be invested into different processes simultaneously, (4) the amount of resources invested into a single process is directly related to the quality of its output, and (5) the amount of resources available at any given point in time is limited. Resource
theory assumes that attention is a \textit{capacity-limited resource}, defined as a component of the processing system which is in limited supply. A structure or channel may be limited if it can only be used by one throughput process at a time. Nonstructural resources are limited in that there exists a finite quantity of resource units that can be invested in one and only one process at a time. In attempting to assess the limits on this capacity, researchers and theorists have generally used \textit{time-sharing paradigms}, which are research paradigms that require the subject to simultaneously complete two different tasks. Time-sharing studies fall under the more general topic of \textit{divided attention}, as the time-sharing paradigms require the subject to divide capacity limited resources between two simultaneous tasks.

\section*{Historical Foundations of Resource Theory}

\textbf{Information Processing Theory}. Information processing theory is a general framework within which investigators examine the passage of information through the cognitive system (Miller, 1983). At some point between the input and the output, the information is subjected to any one or more of several intervening processes. One of these processes is attention.
Miller (1983) cites several cultural and scientific developments over the past 50 or so years that have influenced the surge of interest in cognitive psychology and information processing. Miller states that the combined influence of two factors set the stage for information processing theory. These were: (1) the loss of confidence in the ability of behavioral principles to explain human cognition, and (2) the increasingly mechanistic nature of our developing society.

A flurry of research activity on attention began during the second world war. The war effort in the United States provided the impetus for government funded research in the area of human operating efficiency. The goal of this research was to determine the limits of human processing system's capabilities specifically in relation to target detection and monitoring.

Another source of influence on information processing research came from the field of communication engineering. Technical improvements in communications (e.g., telephone, telegraph, radio, television) suggested that information must be coded for transmission, that channels of communication have a limited capacity, and that information may be transmitted serially or simultaneously. These developments are paralleled in the current research on human
information processing. The field of computer science has had an impact on model building as well. For example, Newell and Simon (1961) put forth a convincing argument that human beings process information in much the same way as computer programs.

**Structural Models.** In the 1950s and 1960s, structural models of attention gained widespread support in cognitive psychology. Structural models assume that the limitation on the human information processing system is structural and characterize it as a channel limitation that requires the system to make a choice about which stimulus inputs will be fully processed. Three landmark models are Broadbent's Filter Model (1958), Treisman's Attenuation Model (1964), and the Deutsch-Norman model, which was first proposed by Deutsch and Deutsch (1963) and later modified by Norman (1968). These early models were proposed in an attempt to explain how we as human beings, with the multitude of stimuli impinging upon our senses, can make active choices about which information will be selected or sent on for further processing, and which information can be disregarded or filtered out.

Broadbent's 1958 model of selective attention is outlined in Figure 1(a). Selective attention refers to how the system makes the initial choice of which information
Figure 4: Early and late selection models (from Kahneman 1973).
will be passed on for further processing. In this model, sensory information is represented in sensory storage in a veridical manner and this storage has a limitless range. Then a filtering mechanism selects one channel (or is set to one channel) and allows only that information to pass on to the limited-capacity channel. This limited capacity channel processes only one information unit at any given time, and subsequent information units are processed serially. Then a response is selected. Support for this model came from the work of Cherry (1953) using a dichotic listening task and a shadowing paradigm. In the shadowing paradigm, attention is controlled by having the subject repeat or shadow the message delivered to a designated ear. However, this model could not account for the finding that certain types of highly meaningful information (e.g., the subject's own name) can be perceived on a nonattended channel.

Treisman's model (1964) was a variant of Broadbent's model. Treisman did not assume that the filtering mechanism operated in an all-or-none fashion. Rather she assumed that information which came in from the senses was attenuated. Treisman assumed that attenuation was necessary because of the limited capacity of the processing channel.

Within this model, Treisman has proposed a hypothetical set of dictionary units, each unit having its own specific
threshold for activation and stimulated by a sensory message. Some of these thresholds for activation were proposed to be permanently lowered (e.g., the activation threshold for one's own name). Also, thresholds for words that the context makes probable are assumed to be lowered temporarily. According to Treisman, lowered thresholds result in information in the nonattended channel being perceived despite attenuation. Support for this model was obtained by Treisman who found that the unattended message would cause greater interference with the attended message if it had similar acoustic or semantic properties. However, Treisman's explanation of the attenuation mechanism was vague. The model did not explain if the mechanism was under the control of some executive process, or, if it worked independently, how the attenuator could make a priori decisions about input relevance. In addition, the notion of an attenuation mechanism is unsubstantiated in our knowledge of the human nervous system (Solso, 1979).

Deutsch and Deutsch (1963) adopted Treisman's notion of dictionary units, but they placed the selective filtering mechanism much later in the system. This model assumes that all items are recognized or processed to a level of meaning and, that only after all sensory data has been given this initial processing does the system become limited in its
capacity. The results of this initial processing can then be used to select certain stimuli for further processing, for storage in memory, or for response. This model places the capacity limits late in the process (see Figure 1b).

Norman (1968) revised this theory by positing that the central dictionary units could accept two types of input: sensory input and pertinence input (i.e., a rank ordering of its importance). At any given moment in time, the unit which has the highest combination of sensory and pertinence inputs will dominate internal events (i.e., perception, awareness, and memory). Each set of encodings is assigned a pertinence value that determines the order of further processing. The added feature of the Deutsch-Norman model is that it offers an explanation of how the system decides what input is relevant. However, the model would predict that a highly relevant message would be detected equally well on either the attended or the unattended channels. Treisman and Geffen (1967) found large differences in subjects' ability to detect a target word in the attended channel (i.e., 87% detected) and the unattended channel (i.e., 6% detected).

**Limited-Capacity Central Processor (LCCP).** The LCCP models assume that the bottleneck or source of interference in processing lies at a central source where executive
decisions are made. These models assume that as a primary task becomes more difficult, it will demand more resources, and these resources will be taken away from a concurrent secondary task if necessary (Knowles, 1963). Moray (1967) assumed that resources could be allocated to any activity or stage of processing by an executive program (i.e., the central executive) that directs attention differentially. Task interference would depend upon the demands on the capacity of the system at a given level of processing and therefore the bottleneck could occur anywhere in the system (Moray, 1967; Kerr, 1973).

Laberge (1975), working within the framework of Deutsch and Deutsch, assumed that early information processing is automatic, occurs in parallel, and is independent of attention. However, subsequent to this automatic encoding of stimulus events, controlled processing takes over. Controlled processing is assumed to require attention and to be necessary for in-depth analysis of the input.

The Atkinson and Shiffrin model of memory (1968) is an LCCP model. In this model, attention is given the position of a control process within the system. Control processes are the master executives of the system in the same way that computer programs direct the processing of information in computer systems. In this model information processing
occurs as information is passed into and out of short term memory.

As an alternative to the Atkinson and Shiffrin model, Craik and Lockhart (1972) proposed Levels of Processing theory. In Levels of Processing theory, the LCCP may deploy attentional resources for maintenance or elaborative rehearsal. When attention is withdrawn from an item, information is assumed to be lost more quickly when it is at an early or surface level of processing and slower if it is at a deeper level of processing.

The concept of channel limitations within the information processing system offered an explanation for some of the research findings on selective attention and filtering. However, the research did not lead to a definitive answer to the question of where in the system the limitation occurred. With the introduction of LCCP models into the literature, there came a focus on higher levels of capacity limitations and executive control over processing resources. Unfortunately, many researchers and theorists have failed to differentiate between the general concept of processing limitations and the more specific concept of attentional resources. The next section is devoted to a more specific conceptualization of attentional resources.
Conceptualizing Attentional Resources

Single-versus-Multiple-Resources. The single-resource model of attention developed out of the LCCP models. This model assumes that there is a single pool of limited attentional resources which serve all processing needs of the system. The upper limit on the resource pool is presumably set, but resource energy can fluctuate somewhat within this limit (Kahneman, 1973). When the demand on resources exceeds the supply, performance becomes limited by resource availability. When the supply can easily meet the demand, performance will not improve by investing more resources.

The multiple-resource model assumes that there is more than one pool of resources and more than one type of resource within the information processing system. It became necessary for Resource Theory to posit such a system when it was discovered that particular types of resource-demanding tasks could be time-shared (i.e., performed simultaneously) without any substantial cost to performance on either task. In addition, experimental manipulations of task difficulty, input modality, type of memory code, and response modality, were found to have effects upon performance which could not be predicted from a single-resource model (Wickens, 1984).
Characterizing Resource Types. Navon and Gopher (1979) describe two types of resources, namely, input resources and processing resources. Input resources are assumed to be invested early in the system's processing and may decrease the demand on later processing. Input resources may include such things as visual resolution, number of extracted features, and quality of retrieved codes, provided that the system can manipulate these. Navon and Gopher present the possibility that these input resources are different from processing resources in that they are limited by subject task parameters\(^1\) instead of capacity.

Wickens (1994) suggested that resources include both a generalized commodity and specific resources tied to structural components of the processing system. He cites Beatty's (1982) work on evoked pupillary responses as well as that of other researchers who have looked at various measures of the brain's reactivity to evoked potentials (Gur & Reivich, 1980; Sokoloff, 1977). This research suggests that there exists a generalized commodity within the processing system that is nonspecific and relates to

---

\(^1\) Subject task parameters characterize the task, the environment, and the properties of the performer that affect task performance. According to Navon and Gopher (1979), these may include the sensory quality of the stimuli, predictability of stimuli, availability and completeness of relevant memory codes, stimulus-response compatibility, response complexity, and amount of previous practice.
consciousness, the bottleneck, and the LCCP (Wickens, 1984).

Wickens also cites the work of Kinsbourne and Hicks (1978) who have suggested a different explanation of resources. These researchers argue that processes are actually in competition for cerebral space in which to function (i.e., competition for neural processing mechanisms). Two tasks which are processing in the same areas of the brain would probably share at least some of the same mechanisms and thus interfere with each other. Kinsbourne and Hicks state that where there are clear divisions between sections of the brain involved in processing (e.g., when the two hemispheres are engaged or when auditory and visual tasks are being processed), the multiple-resources model may account for the data.

Alternatively, Hirst and Kalmar (1987) define resources as a combined set of structures, processes, skills, and reservoirs of fuel. These resources are a part of the information processing system that are available to be drawn upon when needed. Structures refer to processing channels which can place structural limitations on the system. The fuel of the system is the energy component of processing commonly associated with arousal. Processes include learned strategies that can make information processing more efficient (e.g., maintenance rehearsal). The skills of
attention are those which allow the system to keep one line of parallel processing from interfering with another. When an activated channel or pathway stimulates parallel channels or pathways with which they are connected, interference between the stimulated channels, or cross-talk, may occur, resulting in task interference. An appropriate analogy is the increased interference experienced on a telephone party line as opposed to a private line. As the processor learns the skills of attention, he/she will be better able to prevent cross-talk interference. These skills of attention that Hirst and Kalmar address can be explained through the development of efficient automatic processing.

**Attentional Resources and Automatic Processing**

In their seminal work on controlled versus automatic information processing, Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977), address two seemingly qualitatively different modes of processing information. Automatic processing is assumed to operate in parallel and to require little or no investment of attentional resources. Controlled processing is assumed to require a substantial investment of attentional resources.

Schneider and Shiffrin refer to the Atkinson and Shiffrin (1968, 1969) model of memory to explain the
development of automatic processing. In this conceptualization of memory processing, long term memory is viewed as a large and permanent collection of nodes within a network of interconnecting linkages. At all times, most of the nodes are inactive or dormant, and a small subset of the nodes are active. The activated nodes constitute short-term memory. Executive processes control the flow of information between short-term and long-term memory. Each node is characterized as a unit wherein activation of any subunit element activates all other subunit elements. The node may consist of a complex set of elements, as well as response programs and processing programs (see Figure 2). An automatic process develops when the linkages between memory nodes in a frequently used pathway strengthen and become easily and readily activated by input stimulation.

According to Schneider and Shiffrin an automatic process or sequence requires a considerable amount of consistent training to develop and will be difficult to suppress, modify, or ignore. A controlled process, on the other hand, is only temporary, is under the control of the subject, and requires the investment of attentional resources. These authors assume that only one controlled processing sequence can be implemented at a time without interference costs. The controlled processing is costly in
**Figure 2:** Controlled and automatic processing within memory systems (as proposed by Schneider & Shiffrin, 1977).
terms of resources and is thus capacity limited. However, controlled processing does have several benefits since it does not require extensive practice, it can be altered easily to meet task demands, and it can be implemented in novel situations to meet new challenges where automatic processing has not yet developed.

The work of Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) makes a strong case for the differentiation between automatic and controlled processing. These researchers engaged in a series of experimental manipulations using a visual memory-matching task under varying conditions of memory set load, frame size, frame time, and their key manipulation variable, which they termed consistent versus inconsistent mapping. On a consistently mapped block of trials, the memory set items were always from a different set than the distracter set of items. Under these conditions automatic responding developed given sufficient practice at the task. When the memory set items were alternated with distracter set items from trial to trial, automatic processing did not develop as measured by both response accuracy and response latency measures.

Hasher and Zacks (1979) also address the controlled versus automatic distinction in information processing. However, these researchers view automatic processing as an
inherent type of processing which orients us to the routine flow of events in our lives. According to Hasher and Zacks, the human nervous system is wired in a way that maximizes processing of certain types of information, and these types of information include: memory for spatial location, timing of events, frequency of occurrence, and word meanings. These factors are not affected, at least to any appreciable degree, by age, culture, education, early experience, or intelligence. According to this conceptualization, automatic processes: (1) operate continually, (2) cannot be improved with practice, (3) do not require awareness or intention, (4) cannot be willfully inhibited, (5) drain minimal amounts of energy, and (6) provide information which is available to consciousness. Support for this conceptualization of automatic processing comes from research on incidental versus intentional memory for location.

Hasher and Zacks accept Schiffrin and Schneider's conceptualization of accessible effortful processes. Effortful processes are presumed to increase in efficiency with practice and to be under voluntary control. Hasher and Zacks state that effortful processes include such processes as: (1) imagery, (2) mnemonic or elaborative devices, (3) organization and clustering, and (4) rehearsal. Developmentally, automatic processing should be obvious from
early life and reach maximum efficiency sooner than effortful processes (Hasher & Zacks, 1979).

The resource conceptualization of attention offers several explanations for the fact that automatic processing appears to be resource free. One possible explanation is that automatic pathways may be triggered by some particular internal or external event which may have a predetermined set amount of resources allocated to their activation. A second view is that those processes that are thought to be capacity free are only capacity cheap (i.e., they require only a small amount of resources to be executed at a desirable level). The third view is specific to the multiple-resource model and states that automatic processes simply draw from a nonoverlapping pool of resources. These processes, theoretically, do not use conscious resources and therefore do not seem to compete with conscious resources (Navon & Gopher, 1979).

**Characteristics_of_Multiple_Resources**

Research has supported a model of multiple resources that incorporates both specific and generalized attentional resources (Kahneman, 1973; Navon & Gopher, 1979; Gopher & Navon, 1980). The work of Norman and Bobrow (1975) and Navon and Gopher (1979) has characterized the demands that
single and dual-task performance conditions can impose upon the system's limited supply of resources.

**Data_Limitations_versus_Resource_Limitations**. Norman and Bobrow (1975) distinguish between limitations on the processing system imposed by the quality of the input stimulus (i.e., data limitations) and those imposed by the amount of resources available for processing (i.e., resource limitations). When a task is data limited, only an increase in the quality of the data input (e.g., longer duration or better resolution) will result in an increase in performance. When the system becomes overloaded due to insufficient resources, task performance usually shows a gradual degradation. However, if task performance requires some critical set amount of a resource, at some point in the gradual decline in performance a sudden catastrophic failure may be observed.

**Performance_Resource_Function (PRF)**. The PRF relates performance to resource allocation. This function can be continuous, or performance could increase in discrete steps that require set amounts of resources (see Figure 3). Most processes have both data-limited and resource-limited regions. Dual task interference occurs when one task is data-limited (usually the high priority task) and one is
Figure 3: Performance resource function. ($R_{min}$ is the minimum amount of resources needed to initiate processing. $R_{dl}$ is the maximum amount of resources, beyond which processing is data limited. When $R_{min} < r < R_{dl}$, processing is resource limited.)
resource limited (usually the secondary task) and the processing resources demanded by both tasks exceed the capacity limits of the system (Norman & Bobrow, 1975).

**Performance_Operating_Characteristic.** The Performance Operating Characteristic (POC) describes the relationship between performance on two simultaneous tasks (Norman & Bobrow, 1975). When both tasks draw from the same limited pool of resources, the POC indicates how the performance on one task varies with the performance on the other task as the subject invests more or less resources into each task. Figure 4 displays the typical POC function. The POC traces the boundary of joint performance. All combinations of Performance X and Performance Y are possible that lie on the curve or in the area under the curve. All other combinations are impossible for the system.

**Fixed_Proportion_Functions.** Navon and Gopher (1979) have suggested that tasks may have fixed proportion functions which reflect the unchanging requirements for specific combinations of resources (e.g., 2 units of short term memory plus one unit of visual storage capacity equals one unit increase in performance). Given this fixed proportion function, if only one unit of short term memory
Figure 4: Performance operating characteristic. (The northeastern most point (A) on the POC curve represents the most efficient tradeoff of resources.)
capacity is available, performance cannot improve, since the proportions cannot be met.

**Variable Proportion Functions.** Alternatively, some tasks may have variable proportion functions which reflect a more flexible use of resources. These functions occur when there is more than one way to do a task. Usually, there is some optimal composition of resources, but deviations are accepted. In this case, an increase in any one type of resource will usually result in a performance increment since that resource could probably be used in some alternative combination to improve performance (Navon & Gopher, 1979).

**Demand Composition.** The demand composition represents the specific fixed-proportion or variable-proportion compositions needed to obtain a unit increase in performance. If a set threshold amount of resources of one type is necessary to produce a unit performance increase, and that one resource cannot be substituted for by any other resource type, a secondary task drawing from that necessary pool will produce large tradeoff effects (Navon & Gopher, 1979).

**Subjective Substitution Rate.** The subjective substitution rate (Navon & Gopher, 1979) is defined as the
amount of improvement in performance on one task that can be gained by sacrificing one unit of performance on the other task. The subjective substitution rate will not necessarily result in a one to one correspondence between freed units of resource X and increased performance units of Y. A unit of resources moved from Task X and given to Task Y leads to a decrease in the performance of X by an amount that is directly related to how much that unit of resources contributed to performance X and will lead to an increase in performance Y by an amount that is directly related to how much that unit of resource can contribute to performance Y.

Utility. Navon and Gopher (1979) define utility as the maximum level of dual task performance that will be maintained by limited resources, given that supply cannot meet the demand. The subjective substitution rate then represents the utility tradeoff of the tasks, or how much the gain in Py (performance Y) can account for or compensate for the loss in Px (performance X). Typically the utility gained by taking resources away from task X to give to task Y diminishes as more and more resources are transferred. Hence, to compensate for the drastic decline in performance X, performance Y will require more and more improvement. This is termed diminishing marginal utility (see Figure 5).
Figure 5: Diminution of marginal utility. (Rx = resources invested in Task X; Ry = resources invested in Task Y; Px = performance level on Task X; Py = performance level on Task Y.)
The optimal mixture of \( Rx \) (resources invested in \( X \)) and \( Ry \) (resources invested in \( Y \)) is the one that yields the joint performance with the highest utility. In addition, a change in the difficulty level of one of the tasks may change the productivity of a unit of resource such that it may no longer have the same effect it had before under simpler conditions.

**Concurrence Costs and Concurrence Benefits.** A concurrence cost occurs when the dual-task demands on resources during time-sharing (i.e., \( Dxy \)) is greater than the cumulative effect of the single task demands (i.e., \( Dx + Dy \)). The POC will be discontinuous at the point of intersection with the axes if a concurrence cost exists because single task performance will utilize fewer resources than can be predicted from dual task performance even when the primary task is operating at a 100% accuracy level (see Figure 6a).

Concurrence costs may be due to some incompatibility with dual processing such as when the outputs, throughputs or preconditions conflict in some way. In such situations, the performance of one task involves side-effects or even main effects that make the other task more difficult. The examples Navon and Gopher provide include the Stroop Interference Effect (in which incompatible visual and verbal
Figure 6: Concurrence costs and benefits. (X1 = performance level for single-task condition for Task X and Y1 = performance level for single-task condition for Task Y.)
codes conflict) and singing a waltz while dancing a tango (in which response patterns are incompatible). Another source of concurrence cost may be the process of organizing, coordinating, scheduling and allocating resources which may themselves all require the investment of effort.

Alternatively, there may be a concurrence benefit in which case D_{xy} would be smaller than D_x + D_y (see Figure 6b). Concurrence benefits may be explained by the fact that the side-effects or outputs of one process may facilitate the processing of the other task. For example, when two concepts are closely linked in memory because they often occur together, the recognition of one of them will enhance the recognition of the other if it occurs subsequently. These beneficial effects are observed in studies of context effects and forward and simultaneous priming effects. Also two tasks may benefit each other because of some redundancy in the components of the tasks (Navon & Gopher, 1979).

**Dual-Task Integration.** There are indications that given sufficient practice with the dual task situation, the tasks may actually become unified into one task with several components. Resource theory would view this as a most efficient use of resources.
Dual-Task Interference. Time-shared tasks interfere with each other because their demand compositions overlap to some degree and they have to compete for resources that they share. If the types of resources that the two tasks demand are completely separate or disjoint, there should be no interference, and the two tasks should be able to be performed simultaneously. If the two tasks demand all the same resources, the performance tradeoff should be large. When the resources are partially shared, task A will improve if task B has freed a resource which they shared but not if task B has freed a resource which is not common to task A. The tradeoff in cases of partial overlap then is limited by the fact that not all released resources may be relevant to the other task and even if they are relevant, the released resource may not be sufficient to produce a change in performance given the demand composition of the receiving task.

Task Difficulty Manipulations. Resource theory predicts that increasing the difficulty level of a primary task in a time-sharing situation should increase the consumption of shared resource units and decrease the amount of resources available to be allocated to the secondary task.
Navon and Gopher (1979) postulated that difficulty manipulations that place heavier demands on common resources for time-shared tasks should show greater sensitivity to priority manipulation. This is postulated because when a difficult task places a high demand on resources, and the task is of high priority or value, the extra investment should be deemed worthwhile, but if the task is of low priority, the investment of the extra resources will probably not be judged to be worthwhile. Thus difficult tasks should show more dramatic performance changes as a result of priority manipulation.

In addition, manipulating the task difficulty may change the task qualitatively if it has the effect of modifying the relative weights of the various resources in the demand composition. If this happens, increasing task difficulty may not increase the demand on shared resources.

**Practice Effects** - With practice, the POC tends to get higher. This finding may be explained by the fact that practice reduces the dual-task demands on energy resources. Alternatively, practice may result in better coordination between tasks because the system is learning how to utilize its resources more efficiently. Furthermore, practice may serve to unify the two tasks into a functional whole. This may require the system to develop a strategy that minimizes
the overlap in the kinds of resources required by the two tasks.

A Multiple Resources Model

Wickens (1984) proposed a model of resources based upon stages of processing, modalities of input, types of throughput codes, and response modalities (see Figure 7). As Figure 7 depicts, perceptual and central processing rely on common resources that are separate from response processes. This differentiation is supported by the research on P300 latency of the sensory evoked potential (Hoffman, Houck, MacMillan, Simons, & Oatman, 1985). The research has shown that difficulty manipulations, which increase only the difficulty of the response, will not affect a secondary task for which the demands are more cognitive or perceptual in nature (Wickens, 1984).

Reserves are also divided into visual and auditory modalities, spatial and verbal codes, and manual or vocal responses. As Figure 7 represents the model, modalities and codes are specific to encoding processes. Central processes have specific codes as well but are not modality specific. At the response stage, the manual or vocal responses are not tied to input modality or codes and, as such, only two resource pools are proposed.
Figure 7: A proposed dimensional structure of human processing resources (from Wickens, 1984).
Wickens (1984) also presented an alternative conceptualization to the multidimensional resource model outlined in Figure 7. He made these modifications to the original model because the assertion that two tasks drawing on adjacent resource cells should be perfectly time-shared was not substantiated in the research. This new conceptualization represents resources in a hierarchy (see Figure 8). This model assumes that a pool of undifferentiated resources exists as well as smaller pools of resources that are linked to structural components of the system. The generalized commodity is assumed to be what in other models is labelled attention, consciousness, the bottleneck, or the LCCP. The proposition that central resources exist does not detract from the concept of multiple resources but merely denotes the relationship between resource pools and resource types.

Research Support for Resource Theory

Although the research evidence on time-sharing is most consistent with a multiple-resources model, much of the past research has been confounded by failure to consider the possible side-effects of the experimental manipulations, and particularly priority and difficulty manipulations (Navon, 1984). In two well designed studies, Vidulich and Wickens
Undifferentiated Resources

Available to and demanded by all tasks, modalities, codes, & stages as required.

Response Resources

Available to be shared by input modalities or processing codes but not responses.

General Perceptual and Central Resources

Available to be shared between modalities but not between codes.

General Verbal Perceptual Code-Specific Resources

Auditory Modality Specific Resources

Available to be shared by two auditory tasks or two visual tasks but not transferred to another modality.

General Spatial Perceptual Code-Specific Resources

Visual Modality Specific Resources

Figure 8: A hierarchical model of multiple resources.
(1981) and Gopher, Brickner, and Navon (1982) confirmed several of the predictions from multiple resource theory. The studies reviewed in this section were selected because they have manipulated difficulty level and/or emphasis in a manner which would not confound the results obtained.

Vidulich and Wickens (1981) compared the resource allocation policy within and between modalities at the encoding and response stages. A memory search task and a visual tracking task were used. They found that the time-sharing efficiency of the two tasks was inversely related to the amount of resource overlap. This initial finding supports both multiple resource theory and an undifferentiated capacity model with structural limitations. However, other findings in this study provide more direct support for a multiple-resource view. First, when the primary task was auditory-vocal and was time-shared with a visual-manual task, time-sharing was nearly perfect, which is consistent with a multiple-resource model when there is little or no overlap in resources. Second, when input and output modalities matched for the time-shared tasks, the performance tradeoff was greater than when the input and output modalities mismatched. Specifically, they found a greater performance cost for the tracking task when it was time-shared with an auditory search task that required a manual response. This effect was enhanced as the difficulty
of the tracking task increased. Consistent with the multiple-resources model, this finding suggests that there was more interference on dual task performance when the two tasks shared some overlapping resources. These results suggest that as more resources are shared between tasks, there exists a greater degree of exchangeable allocable commodity.

Gopher, Brickner, and Navon (1982) compared time sharing of a digit classification task and a tracking task at three levels of priority manipulation. The digit classification task was made more difficult at a conceptual or a motoric level. The results indicated that the effect of priority was enhanced when the motor response was made more difficult but not when the task was made conceptually more difficult. These authors concluded that the difficulty manipulation on spatial-motor responses increased the demand on the spatial-motor resources which were time shared with the tracking task.

In another study, resource independence between the two hemispheres was investigated. Herdman and Friedman (1985) used a time-sharing paradigm with varying emphasis conditions to assess the performance tradeoff when the two tasks were processed in the same or different hemispheres of the brain. A tone memory task was presented to either the
right or left ear and was paired with a visually presented verbal memory task (i.e., a printed nonsense word). The tradeoff between the two tasks was significant (i.e., the emphasis manipulation resulted in large tradeoffs in task performance) when both tasks were being processed by the left hemisphere but not when the tone task was delivered to the left ear (or right hemisphere).

These selected studies present the case for a multiple resources explanation of processing limitations. The studies reviewed here have attempted to test the limits on the capacity of the system by manipulating the difficulty level of the tasks and the degree to which the resources are shared between the two tasks. The results of these studies have indicated that when input or output modalities match or when throughput codes overlap, there is a greater performance tradeoff between the two tasks.

On the basis of these results, researchers have concluded that more than one pool of attentional resources exists. In addition, it is proposed that more than one type of resource exists. Wickens (1994) posited the existence of a hierarchy of resources which interact with structural components of the system. Various types of processing limitations have been identified in the research on cognitive deficiencies in children. The following section
addresses some specific developmental limitations on processing.

**Developmental Processing Limitations**

The time-sharing research using adult subjects has implicated structural and attentional resource limitations as well as limitations in skills and strategies to account for the observed constraints on information processing. Are there specific constraints on information processing which are uniquely developmental in nature? Past research has suggested that there are some important developmental constraints on attentional capacity and attentional deployment (Gibson, 1969).

Recent research has shown that young children, as opposed to older children and adults, are more haphazard in their search behavior (Vlietstra, 1982), are less efficient at filtering out distractions (Miller & Weiss, 1981; Strutt, Anderson, & Will, 1975; Enns & Gorgus, 1985), and are less efficient at deploying attentional resources on divided attention tasks (Lane, 1979). Several possible explanations have been provided to account for this observed increase in information processing efficiency with age. Several alternative explanations are presented below.
**Functional Operating Space.** One explanation which has been offered to account for developmental changes in attention suggests that resource capacity increases as a function of maturation. Kail and Bisanz (1982) refer to this as the *Growth Hypothesis*. McLaughlin (1963) and Pascual-Leone (1970) were among the first developmental theorists to suggest that mental capacity increases quantitatively with age. More recently, other researchers have found support for quantitative increases in mental capacity with age (Case, 1972; Scardamalia, 1977; Case & Serlin, 1979; Kail, 1985). This finding may be related to the increasing myelination of brain centers, particularly within the reticular activating system (Shaffer, 1985).

**Speed of Processing.** One general source of developmental limitation in information processing lies in the speed of processing (Chi, 1977; Wickens, 1974). Chi and Gallagher (1982) propose two explanations to account for the slower rate of processing observed in young children. One explanation is structural and relates the speed of processing to the capacity of working memory. These researchers state that the capacity of working memory has been shown to be inversely related to the speed of processing in adults and that the developmental limitations on speed of processing is the cause of the observed inferior
performance of children on many memory and problem solving tasks.

The second explanation of developmental differences in speed of processing suggests that children are deficient in terms of strategy use and general knowledge in long-term memory store. It is suggested that children have fewer nodes in memory and fewer associative linkages and that this retards the speed at which pathways and nodes can be activated in comparison with adults. Since these limitations may be overcome with learning and practice, they are thought to be functional limitations as opposed to structural limitations. Whitney (1986) found research support for this contention. Whitney reviewed studies of simple naming latencies, object name versus physical matching, and categorization times, and concluded that speed of semantic memory retrieval was associated with developmental trends in the use of strategies and the organization of semantic memory.

Knowledge Base Changes. Kail and Nisanz (1982) state that the changes that occur in children's representations (i.e., memory schemes) and processes (i.e., mental activities that generate, transform, and manipulate representations) play a major role in the increased efficiency of processing with age. Representations are
thought to exist in the knowledge base as a network of conceptually related items linked associatively. The elements of the representational unit may increase in number such as when new defining features of a concept are learned. In addition, the number of representational units may increase such as when a new concept or vocabulary word is learned. Older children seem to include more information in a chunk than younger children do, which probably results in greater efficiency of processing. Furthermore, change can occur in the relationships between elements and units.

Bjorklund (1987) elaborates on the effects of the knowledge base on memory task performance. He states that age is associated with knowledge base changes which affect the ease with which information in long-term memory can be activated. This increased accessibility in turn affects the amount of attentional resource capacity that is available for other cognitive tasks. Bjorklund posits that knowledge of the items used in a memory task can improve memory performance by: (1) increasing the accessibility of that item, (2) increasing the accessibility to associated items in a resource-cheap manner because linkages are strengthened, and (3) facilitating the use of deliberate strategies which are dependent upon elaborative interconnections and organization (e.g., categorization and elaborative rehearsal).
Roth (1983) showed that knowledge has a large effect on task-specific performance. Roth found that adult superiority in the speed of processing on a chess-related task could be significantly reduced if the children possessed an equivalent amount of prior knowledge of the game. However, this effect was found to be task specific and did not generalize to another task which was nonspecific to the game of chess.

**Development of Strategies.** Kail and Bisanz (1982) state that strategy use has the effect of reducing processing demands on attentional resources. The strategies used to gather, store, and utilize information may become increasingly more sufficient (i.e., more powerful or better able to deal with more information) and more efficient (i.e., it may become easier to match the strategies to situations where they would be useful such that the strategies become more discriminating) with development. Also, processes may undergo changes in the speed of execution which would have the effect of freeing up attentional resources faster (Kail & Bisanz, 1982). However, the implementation of strategies may itself be very resource demanding.

Guttentag (1984) found that children who were classified as spontaneous strategy users could implement a
preferred strategy less effortfully than children who were instructed to use the preferred strategy but were not using it spontaneously. Guttentaq concluded that when given the choice, children may decide not to use a strategy because the implementation of that strategy is deemed to be too resource demanding to be effective. Likewise, Bjorklund and Harnishfeger (1987) found that imposing memory strategies upon young children had the effect of reducing the total amount of mental capacity available for other activities and thereby resulted in only modest gains in memory performance. Total mental capacity was assessed in this experiment by having children engage in a compensatory finger tapping task. Imposing the memory strategy on young children caused a significant decrease in finger tapping with only moderate gains in memory performance.

**Increased Automatization** Shiffrin and Schneider (1977) and Schneider and Shiffrin (1977) have demonstrated how automatic, resource-cheap processing develops in adults given sufficient practice and consistent training. Kail and Bisanz (1982) assume that basic and repetitive processes become more automatic with repetition as well. Automatic processes presumably require fewer attentional resources and thus automatic processing frees up resources to be used elsewhere in the system.
A study done by Lipps Birch (1978) demonstrated that sufficient practice can free up attentional resources in young children. In this study, two groups of eight year old children and one group of 13 year old children performed an auditory matching task and a compensatory motor tracking task as single tasks and then concurrently. One of the eight year old subject groups was given sufficient training to bring their single task performance up to a level to match the 13 year old group before the time-sharing trials.

The results showed that the 8 year old training group was indistinguishable from the 13 year old group both on single-task and time-sharing performance measures. The 8 year old training group appeared to automatize the underlying skills. The 8 year old untrained subjects showed significant single-task differences from both the 8 year old training group and the 13 year old group, and displayed a significantly greater decrement during time-sharing.

Lipps Birch concluded that the single-to-dual task decrement observed in time-sharing performance can be eradicated by improving single-task performance. However, it is unwise to assume that the training that the 8 year old group received equated them with the 13 year old children in the way they performed the task. Multiple resource theory assumes that a task may have a variable proportion function
which would allow the central executive to make use of the available resources in any one of a number of ways in order to meet the task goals. Thus, the trained 8 year olds may have automatized the underlying skills and become more proficient at the task, but the 13 year olds may have used a more efficient strategy, may have unified the two tasks into one, or may have had more resources to allocate to the tasks. Since the 13 year olds in Lipps Birch's study did not have extensive practice with the tasks, it is unlikely that their high performance was due simply to automatization of task-specific skills.

**Changes in Attentional Control.** There are several studies which support the contention that adult subjects can adjust their allocation policy in accordance with task demands in time-sharing situations (Gopher, Navon, & Chillaq, 1977; Wickens & Gopher, 1977). Research has suggested that when the demands on attentional resources exceed the supply, the subject will allow secondary task performance to fall but will try to protect primary task performance (Kahneman, Beatty, & Pollock, 1967; Kantowitz & Knight, 1974, 1976).

A few researchers have used time-sharing designs with emphasis manipulation to assess the effects of age on resource allocation. Schrieff & Knopf (1985), for example,
asked 9 and 13 year old boys to time share two visual tasks. The primary task was a target detection task presented in the center of a display screen. The secondary task was a letter recall task presented in the corners of the display screen. Eye movements were recorded in addition to performance measures. The 13 year old children were found to spend less time focusing on the corners of the display when instructed to emphasize target detection and they correctly recalled more letters when instructed to complete both tasks. Schiff and Knopp concluded that the ability to allocate attention in accordance with task demands increases with age. Two possible explanations come immediately to mind. Either the central executive has obtained more control over allocation of resources by age 13 or the amount of resources available to be allocated increases between the ages of 9 and 13. Both explanations are plausible and are not mutually exclusive.

In an earlier study, Lane (1979) found support for the contention that the central executive has less control over resource allocation at younger ages. In this study, ten children in grades 2 and 4 and ten college students time-shared an auditory memory task and a visual memory task under varying payoff conditions (i.e., with success on the two tasks rewarded differentially). Lane found that none of
the grade 2 subjects responded differentially to payoff manipulation, whereas approximately half of the grade 4 subjects and all of the college students responded differentially. Furthermore, the results cannot be accounted for on the basis of resource capacity limitations since this was equated across developmental level. Lane concluded that the ability to allocate attention is a developmental skill that is separate from processing capacity limitations. However, an alternative explanation for these results may be that the implementation of the allocation policy placed a demand on the processing capacity of the younger children that they could not meet.

Summary of Developmental Limitations on Processing

Several developmental limitations on processing have been discussed. These limitations include: the knowledge stored in a semantic or episodic form in long-term memory, the increased strength of association and increased organization in long-term memory that is assumed to occur with learning, the increasing control over pathway activation that prevents cross-talk, the development of automatic pathway activation that results from extended practice, the inherent predispositions for automatic processing, the level of cortical arousal at any given
moment in time and its range of variability, and the neural
structures which support processing (i.e., the neurons, the
dendritic growth, the formation of synapses, and the
myelinization process). These limitations on processing can
be characterized as a multidimensional set of factors that
coexist and progress developmentally toward increasing
efficiency. The developmental progression of this set of
factors allows the human being to become a better processor
of information as a function of growth and experience.

Multiple_Resources_and_Developmental_Research

Navon (1984, 1985) and Navon and Gopher (1979) have
proposed that the strongest support for resource theory
comes from studies of divided attention that have
manipulated both primary and secondary task difficulty and
the allocation policy of the subject. A study so designed
will presumably allow the researcher to assess the available
resources of the system. Navon states that the priority
manipulation must be done in a manner that does not bias the
subject toward merely compliance with examiner expectations.
Priority should be manipulated in a manner that maximizes
the probability that the subject will utilize the full
capacity of his/her resources in completing the tasks.
Wickens (1984) pointed out that confusions have arisen in
time-sharing research which has failed to take into account both the overlapping structural limitations and the nonstructural attentional limitations on processing. In order to assess the attentional capacity of the system, research designs must consider the possible overlap of processing structures.

The only developmental research which has approximated such a controlled design is the previously described study completed by Lane (1979). Lane asked second and fourth grade children and adults to time-share an auditory and a visual memory task. As previously cited, a large amount of variability was observed in the grade 4 subjects in their ability to allocate attention differentially according to payoff. Lane interpreted these findings as indication of a transitional period in the establishment of executive control over attentional deployment.

Within this study, the difficulty levels of the two tasks were set in advance for each subject. One task was a binaurally presented verbal memory task involving 8 animal names and requiring a verbal response. The other task was a visually presented memory task involving 10 geometric designs and requiring a manual response (i.e., the child had to point to the designs on a master card in the order in which they were presented). Priority was manipulated by
setting one task at a higher point value than the other task. The priority manipulation was reversed between sessions.

Lane found that the priority manipulation had no effect on the performance of the second grade children, but had an effect on performance for about half of the grade four subjects and all of the college students. The mean difference between the proportion correct on the primary and secondary task was 1% for the second grade children, 19% for the fourth grade children, and 24% for the college students. A significant Age X Payoff interaction was found ($F = 6.92, p < .01$). Thus, there appears to be some developmental limitation in the ability to allocate attention differentially according to payoff. Lane suggested that this limitation is overcome somewhere around the age of 9 or 10. However, the age range studied by Lane did not allow him to determine if he had truly found a developmental transitional period, since his next oldest age group was an adult sample. In addition, there was a discrepancy between Lane's findings and the results obtained by Lipps Birch (1976). Lipps Birch found that grade 2 children could differentially allocate attention in accordance with payoff, whereas Lane found that grade 2 children could not allocate resources differentially in accordance with payoff.
Lane (1979) has suggested that Lipps Birch's design was confounded by a failure to randomize the conditions (i.e., equal payoff always came before primary task payoff) and as such, Lipps Birch's findings may have been confounded by practice effects. However, since Lane did not completely randomize his conditions either, the same criticism may apply to Lane's work. Lane (1979) did not directly assess equal payoff but used a no payoff condition as an initial practice session. Another explanation for the observed discrepancy in these research findings may lie in the method of emphasis manipulation. Lipps Birch (1976) told the children that one task was more important than the other, that they should pay more attention to the important task, and that they should improve their performance on this task relative to the equal-emphasis condition. This manipulation would not necessarily maximize joint performance. A third explanation may lie in the choice of tasks used. Lipps Birch used a compensatory motor tracking task and a category matching task. These two tasks may not have been as cognitively demanding as Lane's memory tasks and may have allowed the child to implement a resource demanding allocation policy.

The research to date on the multiple resource model, as it applies to developmental psychology, has been minimal.
With the exception of Lane's (1979) study, researchers have not used adequate controls to assess time-sharing ability in young children. The proposed study attempts to overcome some of the shortcomings in past research in order to assess the validity of the multiple resource model for developmental psychology.

The Present Study

The purpose of the present study is to assess the validity of the multiple resource model as a framework for conceptualizing developmental changes in processing limitations. The study utilizes the same general methodology as Lane (1979) and Vidulich and Wickens (1981) to assess the validity of the model of multiple resources. Thus, this study is designed to manipulate both the level of difficulty of each task and the allocation policy of the subject in a manner that is designed to maximize the performance tradeoff.

The study addresses developmental changes in attentional resources and attentional deployment across four age levels. A time-sharing paradigm is used to assess the validity of the assumptions underlying resource theory. The study is designed to circumvent many of the confounding influences that have been present in previous research.
The specific developmental limitations on processing (i.e., neural circuitry, knowledge base differences, speed of processing, and mental operating space) are controlled for by determining the difficulty level of the tasks individually for each subject. The procedure used for this purpose is adapted from Lane (1979). Lane assessed each child individually and set the difficult version of each task at a criterion level of performance.

Task priority is established in a manner similar to Lane (1979) in order to assess the subjects' allocation policy. However, unlike Lane's design, the payoff manipulation involves an equal emphasis condition to directly assess the possible developmental deficiencies in resource allocation found by Lane. All manipulations of priority and task difficulty occur within subjects and follow a counterbalanced order across subjects.

Strategy use is another developmental variable which could be confounded with attentional resources. The spontaneous use of strategy is controlled through the initial establishment of difficulty level for each child and the use of a within subjects design. If practice at the task(s) has the effect of increasing the probability of strategy use, these practice effects can be controlled statistically. The choice of strategy is somewhat limited.
by the nature of the items on the auditory and visual memory tasks. Rote rehearsal and chunking strategies may improve performance on the tasks while other strategies may be too resource demanding to be effective. In addition, the tasks were chosen so as to maximize the probability of differential use of underlying neural structures (i.e., different input channels, different response modes, different throughput codes).

The study is designed to assess age-related changes in the use of attentional resources by manipulating the difficulty level of two time-shared tasks and the priority or value of each task in relation to efficient processing.

**Predictions from Resource Theory**

Resource theory assumes that most dual-task situations involve a concurrence cost. Single resource theory predicts that there will always be a concurrence cost if the two tasks cannot be integrated in some way. Multiple resource theory predicts that tasks that draw from nonoverlapping resource pools may be time-shared efficiently with little or no cost of concurrence. The multiple resource model delineated by Wickens (1984) is a hierarchical model which posits that a generalized commodity (i.e., attention) may exist at some level as a common undifferentiated resource
pool and at other levels as specific resource pools associated with specific input channels, specific throughput codes, specific stages of processing, and specific response modalities. Wickens proposed that these specific resource pools are a counterpart to the satellite structural limitations proposed by Kahneman (1973). In the present study, the tasks were chosen in an attempt to maximize the differential use of structural resources. If there is a general pool of attentional resources at some level, from which all resource-demanding cognitive processes must draw, a single-to-dual task decrement should be observed.

Resource theory also predicts that increasing the level of difficulty of the primary task should magnify the effects of priority manipulations if the two tasks are drawing from some common resource pool (i.e., more effort should be placed on the high priority task at a higher cost to the low priority task when the high priority task is more difficult). Given these conditions, the performance tradeoff between the two tasks should be large (i.e., performance on the secondary task should show a significant decline). At low levels of difficulty, the high priority task may be easily maintained without a great cost to the low priority task.
Resource theory predicts that subjects can voluntarily allocate attentional resources in accordance with payoff or priority manipulations. However, Lane (1979) demonstrated that younger children have more difficulty than older children in manipulating their resources to maximize payoff. If the establishment of central control shows developmental progression, the grade 2 children should display the least efficient utility tradeoff whereas the adult subjects should display the best utility tradeoff. Thus, it is predicted that younger children will be less likely to protect primary task performance as the primary task becomes more difficult. In addition, younger children should be less likely to display performance level changes in accordance with the payoff manipulation.

Hypotheses

Hypothesis_1. It is expected that subjects of all ages will demonstrate a single-to-dual task decrement in performance. When the tasks are difficult, this decrement will be large and when the tasks are easy, the decrement will be significantly smaller.

Hypothesis_2. Differential performance on the high priority and low priority task is expected to be minimal for the grade 2 children and maximum for the adult subjects.
Hypothesis 3. Performance on the low priority task is expected to decline when the high priority task increases in difficulty. This effect is expected to be greatest for the adult subjects and much smaller or nonapparent in the grade two subjects.

Hypothesis 4. The utility tradeoff, measured by the total number of points or tokens earned, is expected to be highest for the adults and lowest for the grade two children.
CHAPTER II

METHOD

Subjects

Twelve students from each of grades 2, 5, and 8 were recruited from a local elementary school, and twelve undergraduate students were recruited from undergraduate psychology courses at the University of Windsor. The grade school students were from a predominantly middle-class neighborhood. Parental permission was obtained for the children and adolescents who participated in the study (see Appendices A and B). The mean age for the Grade 2 sample was 7.87 years (range = 7.42 to 8.25 years), for the Grade 5 sample was 10.84 years (range = 10.33 to 11.25 years), for the Grade 8 sample was 13.80 years (range = 13.33 to 14.33 years), and for the University sample was 21.92 years (range = 19 to 26 years).

The grade school students who participated in the study were selected by their classroom teachers according to the following criteria for participation: (1) No diagnosed or suspected exceptionalities (i.e., Learning Disabilities, Mental Retardation, Attention Deficit Disorder, Giftedness, or brain injury) and (2) No auditory or vision deficits on
school-administered standard screening tests, or corrected to normal vision and hearing. Appendix C provides the statement of limitations for participation which was given to the classroom teachers.

Design

The design of the study consists of a factorial combination of Grade (second grade, fourth grade, eighth grade, and undergraduate university students), Visual Task Difficulty (easy and difficult), Auditory Task Difficulty (easy and difficult), and Payoff (high, low, or equal priority). All variables except Grade were manipulated within subjects (see Table 1).

Each subject was required to respond to 3 trials within each of the 12 combinations of within-subject variables. The twelve within subjects conditions were counterbalanced for each subject using a diagram-balanced Latin square for an even number of levels (Keppel, 1982; Namboodiri, 1972). Table 2 presents the Latin-square design. A total of 72 responses (i.e., 2 tasks X 3 trials X 12 conditions) were provided by each subject within the dual-task situation. Baseline measures of single task performance were taken at 3 different times in order to assess the stability of single-task performance. Each of the single-task
Table 1

Within-Subject Factorial Combinations for the N=12 Repeated Conditions

<table>
<thead>
<tr>
<th>(C) Difficulty Level of Auditory Task</th>
<th>(B) Difficulty Level of Visual Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy (C1)</td>
<td>Easy (B1)</td>
</tr>
<tr>
<td>C1  C1  C1</td>
<td>C1  C1  C1</td>
</tr>
<tr>
<td>D1  D2  D3</td>
<td>D1  D2  D3</td>
</tr>
<tr>
<td>(1)a      (2)  (3)</td>
<td>(4)  (5)  (6)</td>
</tr>
<tr>
<td>Hard (C2)</td>
<td></td>
</tr>
<tr>
<td>C2  C2  C2</td>
<td>C2  C2  C2</td>
</tr>
<tr>
<td>D1  D2  D3</td>
<td>D1  D2  D3</td>
</tr>
<tr>
<td>(7)  (8)  (9)</td>
<td>(10)  (11)  (12)</td>
</tr>
<tr>
<td>D1  D2  D3</td>
<td>D1  D2  D3</td>
</tr>
</tbody>
</table>

Payoff Condition (D)

\[\text{Numbers in brackets refer to the 12 conditions repeated within subjects.}\]
\[\text{a) The visual task has a point value of four and the auditory task has a point value of one.}\]
\[\text{b) The two tasks are both valued at two points.}\]
\[\text{c) The auditory task has a point value of four and the visual task has a point value of one.}\]
Table 2

**Diagram-Balanced Latin Square for N=12 Within-Subject Conditions.**

<table>
<thead>
<tr>
<th>Subject</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>12</th>
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<td>3</td>
<td>8</td>
<td>4</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

**Note.** The entries in the body of the table refer to the 12 within-subject conditions as depicted in Table 1.
assessments were composed of 3 trials at each level of task difficulty.

Stimuli and Materials

Twelve 3- to 5-letter monosyllabic nouns were chosen as the auditory stimuli on the basis of category distinctiveness (Battig & Montague, 1969; Posnansky, 1978), low association values (Palemero & Jenkins, 1964; Keppel & Strand, 1970; Marshall & Cofer, 1970), and a high frequency of occurrence (Thorndike, 1932; Caroll, Davies, & Richman, 1971). These twelve words were: corn, snow, shirt, pine, book, bus, lake, head, door, fork, doll, and cat. A random system of item selection was used to construct lists varying from 2 to 10 items for the memory task. These words were presented to the subjects by audio tape at the rate of one word per second.

Eight graphic designs were used as the visual stimuli for the visual memory task. These designs are items from the Visual Sequential Memory subtest of the Illinois Test of Psycholinguistic Ability (Kirk, McCarthy, & Kirk, 1968). These designs are nonmeaningful figures, and as such, were assumed to be difficult to encode verbally. A random system of item selection was used to construct the visual task trials. These stimuli were presented on cards and required
a manual response (i.e., the subject selected the specific designs they had seen from the entire set of designs displayed in a randomized order on plastic chips and placed them in the same order in which they appeared on the stimulus card).

**Procedure**

Students in grades 2, 5, and 8 were tested individually in a separate room within the school setting. The university students were tested in a quiet room on the university campus. All subjects were required to participate in two separate sessions.

**Session 1.** The first session required approximately 30-40 minutes. The students were told that the researcher was interested in how memory and attention change with age. They were also informed of the incentive system and the rewards they could expect for their efforts at the end of the study. The incentives were used to maintain motivation and interest in the tasks. The first step in the procedure was to provide the students with an opportunity to familiarize themselves with the stimuli that would be part of the memory tasks. For the auditory task, the Grade 2 and Grade 5 children looked at pictures of the words as they were being read aloud by the examiner and the Grade 8 and
University students looked at the word list as the words were read by the examiner. For the visual task, all subjects matched the visual designs to a practice card (see Appendices D and E for the specific instructions for each grade level).

The second step was to establish the difficulty level for each task for each subject. Testing began with the grade 2 subjects at the two word level, with the grade 5 subjects at the three word level, and with the grade 8 and university students at the four word level. Testing was continued until the subject failed three consecutive trials or three out of a possible four trials. The difficult task was set at the criterion of three out of four correct responses. The easy task was set at two words less than the criterion\(^2\). For example, if the child reached the set criterion at the four word level, this would be the difficult level of the task for that child and the two word level would be the easy level of the task for that child.

\(^2\) In several instances, the two levels below criterion for the easy version of the task was not possible as the subject’s criterion performance was near the floor of the task difficulty manipulation. A minimal level of difficulty for the easy version of the auditory task was 2 words. For some subjects, this meant that there was only one level between the easy and difficult versions of the task.
The difficulty level of the visual task was established in a similar manner. A stimulus card was presented for five seconds at a level of 2 symbols (i.e., designs) per card for the grade 2 students, three symbols per card for the grade 5 students, and 4 symbols per card for the grade 8 and university students. The subjects were required to choose the symbols that they had just seen and align them in the same order as on the stimulus card. After the card was withdrawn, the subject was cued to begin his/her response. The same criterion was used to set the difficulty levels as in the auditory memory task.

The third step in the procedure, following the establishment of the difficulty levels for each task, was to administer the easy and difficult versions of each task individually to assess single-task performance. Three trials at each level of difficulty for each task were provided. Each correct trial was rewarded with one point.

3 The easiest visual task level was one symbol and, as a result, there were several cases for which there was only one level between the easy and difficult versions of the task. This occurred most frequently with the grade 2 children.

4 In order to control for motivation effects, the students earned rewards for correct performance. The second and fifth grade students earned tokens for correct performance which could be exchanged for small prizes. The grade 8 and university students earned points for correct performance that were tallied on a sheet of paper. These points were valued at 2 cents per point and were to be exchanged for money at the completion of the study. A similar procedure was used by Lane (1979) to maintain
(or token). If the subject obtained all 3 points for the difficult level task, the next level of difficulty was attempted. If the subject met the criterion at this new level of performance, that subject's difficulty level was increased accordingly. If the subject failed to meet the criterion at this level, the difficulty level remained unchanged. This procedure is designed to control for practice and motivational effects.

The remainder of the first session was devoted to dual-task practice trials. There was no payoff for these practice trials, but the children were encouraged to practice the four combinations of task difficulty so that they could do a good job in the next session. One trial in each of the four conditions of task difficulty was provided. This practice time was provided in order to familiarize the subjects with the expectations in the dual-task condition.

Session 2: The second session required between 50 and 60 minutes. In most instances, the second session was conducted 2 to 3 days following the first session. In all instances, the time-lag was less than one week. In the second session the subjects were reminded of the rewards for good performance. The first step in the second session was to reintroduce the stimuli on the memory tasks. The second

motivation.
step was to readminister the single-task trials. The third step was to provide the 4 dual-task practice trials again. The procedure up to this point was exactly the same as in the first session. The subjects were then introduced to the payoff manipulation and told that the goal was to get as many points as possible. The twelve dual-task conditions were administered in a counterbalanced order across subjects. A readministration of the single-task trials was completed after the 12 dual-task conditions in order to establish the possible effects of practice on single-task performance. A detailed description of the specific procedures and instructions provided for each grade level can be found in Appendices D and E.

The final step in the procedure was to count the number of points (or tokens) that the subjects earned and to distribute the rewards.

Analyses

The data were analyzed using Statistical Analysis System programs (SAS Institute, 1985). The time-sharing data were analyzed using a repeated measures analysis of variance (ANOVA) procedure. Practice effects were removed statistically using the method suggested by Keppel (1982) for a Latin square design. This method subtracts a calculated position-practice effect from each individual
score in the Latin square matrix (see Appendix F for more details). This procedure requires that the degrees of freedom for the error term be adjusted in order to compensate for the loss of information caused through the removal of practice effects from the data (Keppel, 1982, pp. 461).

Hypotheses 1 predicts that the imposed time-sharing will produce some cost to task performance. In order to assess this expected decline in performance, a 4 Grade X 2 Auditory Task Difficulty X 2 Visual Task Difficulty X 2 Task Condition (i.e., single and dual) ANOVA was conducted on the performance scores for both dependent measures (i.e., the visual and auditory tasks). Scheffe post hoc means comparisons were performed on the ANOVA main effects. The significant interactions were analyzed by conducting tests of simple effects and simple effects comparisons (Keppel, 1982).

Hypotheses 2 and 3 predict that the payoff manipulation will affect the age groups differentially, and will interact with task difficulty. In order to assess the effect of the

5 The performance scores used in these analyses are practice-corrected percentage scores based upon the number of correctly recalled items in the correct position (see Appendix F for more details). Only the equal emphasis time-shared condition was compared to the single-task condition to prevent the effect of time-sharing from being confounded with the priority manipulation (see Appendix F for more details).
payoff manipulation, a 4 Grade (i.e., 2, 5, 8, and university freshmen) x 2 Auditory Task Difficulty (i.e., easy and difficult) x 2 Visual Task Difficulty (i.e., easy and difficult) x 3 Payoff (i.e., high, low, and even) ANOVA procedure was performed on the visual and auditory memory task scores. Scheffe post hoc means comparisons were performed on all significant main effects. The significant interactions were broken down into partial interactions and were further delineated by conducting interaction contrasts and simple effects comparisons.

Hypothesis 4 predicts that the utility scores\(^6\) will be dependent upon grade level. A one-way ANOVA was performed on the total point score across the 12 dual-task conditions. The independent variable in this analysis was grade. In addition, a 4 Grade x 2 Auditory Task Difficulty x 2 Visual Task Difficulty x 3 Payoff repeated measures ANOVA was performed on the practice-corrected within-condition utility scores. Post hoc analyses included Scheffe means comparisons on the significant main effects and simple effects comparisons on the significant interaction effects.

---

\(^6\) The utility measure is the total point score earned by the subjects within and across the 12 dual-task conditions (see Appendix F for more details on the calculation of within-condition utility scores).
CHAPTER III

RESULTS

The results are presented in order of the hypothesized effects. The results of the preliminary analyses on the ORDER variable which designated the counterbalanced order of conditions within the Latin square are presented in Appendix G.

Analyses of Hypothesized Effects

Hypothesis 1. A single-to-dual task decrement in performance was expected for all subjects. This performance decrement was expected to be significantly larger when the difficult versions of the tasks were time-shared, than when the easier versions of the tasks were time-shared.

A 4 Grade X 2 Auditory Task Difficulty (ATD) X 2 Visual Task Difficulty (VTD) X 2 Task Condition (TCOND—single versus dual) ANOVA was performed on the two dependent measures (i.e., auditory task performance and visual task performance). Tables 3 and 4 present the results of these analyses. Support for the hypothesis was found in the significant main effect for Task Condition both on the
Table 3

Analysis of Variance Summary Table for the GRADE X ATD X VTD X TASK_CONDITION Analysis of Auditory Task Performance.

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>df</th>
<th>ANOVA SS</th>
<th>F</th>
<th>p &lt; F</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2.45089</td>
<td>5.85</td>
<td>.01</td>
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<td>ATD</td>
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<td>.511146</td>
<td>39.67</td>
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</tr>
<tr>
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<td>n.s.</td>
</tr>
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<td>.025</td>
</tr>
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<td>n.s.</td>
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<td>.025</td>
</tr>
<tr>
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<td>2.43</td>
<td>n.s.</td>
</tr>
<tr>
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<td>.001376</td>
<td>.06</td>
<td>n.s.</td>
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<td>.22</td>
<td>n.s.</td>
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<td>.002999</td>
<td>.12</td>
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</tr>
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<td>n.s.</td>
</tr>
<tr>
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<td>.001376</td>
<td>.06</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Note: GRADE = GRADES (2, 5, 8 undergraduates)
ATD = Auditory Task Difficulty (easy and difficult)
VTD = Visual Task Difficulty (easy and difficult)
TCOND = Task Condition (single versus dual)
Table 4

Analysis of Variance Summary Table for the GRADE X ATD X VTD X TASK_CONDITION Analysis on Visual Task Performance*

<table>
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<tr>
<th>SOURCE</th>
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<th>ANOVA SS</th>
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<tbody>
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<td>.001</td>
</tr>
<tr>
<td>VTD</td>
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<td>2.794838</td>
<td>128.07</td>
<td>.001</td>
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<tr>
<td>TCOND</td>
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<td>6.110504</td>
<td>209.85</td>
<td>.001</td>
</tr>
<tr>
<td>GRADE * ATD</td>
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<td>n.s.</td>
</tr>
<tr>
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</tr>
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<td>n.s.</td>
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<td>0.009600</td>
<td>.52</td>
<td>n.s.</td>
</tr>
<tr>
<td>ATD * TCOND</td>
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<td>4.40104</td>
<td>22.61</td>
<td>.001</td>
</tr>
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<td>1.149438</td>
<td>47.18</td>
<td>.001</td>
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<td>0.097315</td>
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<td>n.s.</td>
</tr>
<tr>
<td>GRADE * ATD * TCOND</td>
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<td>0.010652</td>
<td>.18</td>
<td>n.s.</td>
</tr>
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<td>1.04865</td>
<td>1.44</td>
<td>n.s.</td>
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<td>0.009600</td>
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<tr>
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<td>1.76</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Note: GRADE = GRADES (2, 3, 6, undergraduates)
ATD = Auditory Task Difficulty (easy and difficult)
VTD = Visual Task Difficulty (easy and difficult)
TCOND = Task Condition (single versus dual)
auditory performance measure ($F(1, 40) = 15.87, p < .001$) and on the visual performance measure ($F(1, 40) = 209.85, p < .001$). Scheffe mean comparisons indicated the expected direction of mean differences. Auditory task performance in the single task condition ($M = .98$) was significantly higher than in the dual task condition ($M = .93, p < .01$).

Similarly, visual task performance in the single task condition ($M = .97$) was significantly higher than in the dual task condition ($M = .71, p < .01$).

The Task Condition X Task Difficulty interactions provided support for the hypothesized effect of the task difficulty manipulation. The TCOND X VTD interaction ($F(1, 40) = 47.18, p < .001$), and the TCOND X ATD interaction ($F(1, 40) = 22.61, p < .001$) were both significant on the visual performance measure. Figure 9 presents the TCOND X VTD interaction effects on the visual memory task. The simple effect of Task Condition (single versus dual) when the visual task was easy ($F(1, 40) = 41.80, p < .001$) and when the visual task was difficult ($F(1, 40) = 183.65, p < .001$) were both significant. Both versions of the task were negatively affected by the time-sharing, however, the effect on the difficult version of the task was more dramatic. Figure 10 presents the ATD effects on the visual performance measure for the dual-task condition.
Figure 2: Mean percentage scores on the visual memory task by task condition and difficulty level of the visual task.
Figure 10: Mean percentage scores on the visual memory task by difficulty level of the auditory task.
As Figure 10 suggests, the visual performance decrement from single to dual task conditions was affected more dramatically by the difficult version of the auditory task. The simple effects of task condition (single versus dual) at the easy version of the auditory task ($F(1, 40) = 99.42, \ p < .001$) and at the difficult version of the auditory task ($F(1, 40) = 142.78, \ p < .001$) were both significant.

The TCOND X ATD interaction was moderately significant on the auditory performance measure ($F(1, 40) = 6.72, \ p < .025$). Figure 11 presents the interaction effects graphically. The simple effects of task condition (single versus dual) at the difficult version of the auditory task ($F(1, 40) = 14.19, \ p < .001$) and at the easier version of the auditory task ($F(1, 40) = 4.25, \ p < .05$) were both significant. The single-to-dual task decrement is marginally significant for the easier version of the auditory task and highly significant for the difficult version. Although visual task performance was susceptible to changes in the difficulty level of the auditory task, the auditory task performance was not susceptible to changes in visual task difficulty. This latter interaction (i.e., VTDX TCOND) was not significant and may reflect a bias toward protecting auditory task performance.
Figure 11: Mean percentage scores on the auditory memory task by task condition and difficulty level of the auditory task.
The interaction between Grade and Task Condition was not significant on either dependent measure.

**Hypothesis 2.** The second hypothesis predicted that the priority manipulation would affect performance differentially across the age groups. Specifically, it was predicted that the Grade 2 children would show the least performance tradeoff to protect the high priority task, and that the adult subjects would display the largest performance tradeoff to protect the high priority task.

The 4 GRADE X 2 ATD X 2 VTD X 3 PAYOFF ANOVA indicated a significant GRADE X PAYOFF interaction effect for both the auditory \( F(6, 80) = 5.06, p < .001 \) and visual \( F(6, 80) = 10.89, p < .001 \) performance measures (see Tables 5 and 6). Figure 12 presents the GRADE X PAYOFF interaction on the visual task performance measure.

The simple effects of the payoff manipulation were significant at the Grade 2 level \( F(2, 20) = 7.57, p < .01 \), the Grade 8 level \( F(2, 20) = 11.93, p < .001 \), and the University level \( F(2, 20) = 31.47, p < .001 \) but not at the Grade 5 level \( F(2, 20) = 1.32, p > .10 \). The high versus low payoff manipulation was contrasted for each grade. In this simple effects analysis, the equal emphasis condition was not included. The payoff comparison (high versus low task priority) was significant at the Grade 2 level \( F(1, \)
Table 5

Analysis of Variance Summary Table for the GRADE X ATD X VTD X PAYOFF Analysis on Auditory Task Performance

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>df</th>
<th>ANOVA SS</th>
<th>F</th>
<th>p &lt; F</th>
</tr>
</thead>
<tbody>
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<td>GRADE</td>
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<td>.995463</td>
<td>6.38</td>
<td>.01</td>
</tr>
<tr>
<td>ATD</td>
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<td>2.513546</td>
<td>63.22</td>
<td>.001</td>
</tr>
<tr>
<td>VTD</td>
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<td>.435925</td>
<td>19.65</td>
<td>.001</td>
</tr>
<tr>
<td>PAY</td>
<td>2</td>
<td>.952326</td>
<td>17.86</td>
<td>.001</td>
</tr>
<tr>
<td>GRADE*ATD</td>
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<td>.202332</td>
<td>2.24</td>
<td>n.s.</td>
</tr>
<tr>
<td>GRADE*VTD</td>
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<td>1.93</td>
<td>n.s.</td>
</tr>
<tr>
<td>GRADE*PAY</td>
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<td>.803270</td>
<td>5.06</td>
<td>.001</td>
</tr>
<tr>
<td>ATD*VTD</td>
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<td>1.33</td>
<td>n.s.</td>
</tr>
<tr>
<td>ATD*PAY</td>
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<td>.176319</td>
<td>5.25</td>
<td>.01</td>
</tr>
<tr>
<td>VTD*PAY</td>
<td>2</td>
<td>.336544</td>
<td>11.05</td>
<td>.001</td>
</tr>
<tr>
<td>GRADE<em>ATD</em>VTD</td>
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<tr>
<td>GRADE<em>ATD</em>PAY</td>
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<tr>
<td>GRADE<em>VTD</em>PAY</td>
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<tr>
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<td>6</td>
<td>.055698</td>
<td>.65</td>
<td>n.s.</td>
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</tbody>
</table>

**Note:** GRADE = GRADES (2, 5, 8, undergraduates)  
ATD = Auditory Task Difficulty (easy and difficult)  
VTD = Visual Task Difficulty (easy and difficult)  
PAY = Priority Manipulation (auditory high-visual low, visual high-auditory low, and equal emphasis)
Table 6

Analysis of Variance Summary Table for the GRADE X ATD X VTD X PAYOFF Analysis on Visual Task Performance.

<table>
<thead>
<tr>
<th>SOURCE</th>
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<th>ANOVA SS</th>
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<th>p &lt; F</th>
</tr>
</thead>
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<td>.11</td>
<td>n.s.</td>
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<td>.001</td>
</tr>
<tr>
<td>ATD*VTD</td>
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<td>.009917</td>
<td>.37</td>
<td>n.s.</td>
</tr>
<tr>
<td>ATD*PAY</td>
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<td>.001</td>
</tr>
<tr>
<td>VTD*PAY</td>
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<td>1.44</td>
<td>n.s.</td>
</tr>
<tr>
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<td>n.s.</td>
</tr>
<tr>
<td>GRADE<em>ATD</em>PAY</td>
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<td>.55</td>
<td>n.s.</td>
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<td>.025</td>
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<td>n.s.</td>
</tr>
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<td>.546880</td>
<td>2.90</td>
<td>.025</td>
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</table>

Note: GRADE = GRADES (2, 5, 8, undergraduates)  
ATD = Auditory Task Difficulty (easy and difficult)  
VTD = Visual Task Difficulty (easy and difficult)  
PAY = Priority Manipulation (auditory high-visual low, visual high-auditory low, and equal emphasis)
Figure 12: Mean percentage scores on the visual memory task by task priority (payoff) and grade level.
10) = 6.56, p < .05), the Grade 8 level (F(1, 10) = 15.41, p < .01), and the University level (F(1, 10) = 43.73, p < .001). Clearly the payoff manipulation had the most significant effect on the university students. The Grade 8 students showed a similar pattern to the university students, and the Grade 5 students showed a slight but nonsignificant differential performance when the visual task was of high priority as opposed to low priority. The Grade 2 children failed to demonstrate the expected pattern of response to the priority manipulation and obtained the lowest scores on the visual task when that task was worth more points.

Figure 13 presents the same GRADE x PAYOFF interaction on the auditory performance measure. This figure demonstrates that only the Grade 3 and University students performed differentially on the auditory task according to the payoff schedule. The simple effects of payoff at the Grade 2 level (F(2, 20) = .58, p > .10) and at the Grade 5 level (F(2, 20) = 1.41, p > .10) were not significant. However, the simple effects of payoff at the Grade 8 level (F(2, 20) = 9.25, p < .01), and at the University level (F(2, 20) = 10.32, p < .001) were significant. The payoff comparison (i.e., low versus high priority) was also significant at the Grade 8 level (F(1, 10) = 10.77, p < .01).
Figure 13: Mean percentage scores on the auditory memory task by task priority (payoff) and grade level.
and at the University level [$F(1, 10) = 10.56, p < .01$].

The Grade 2 and Grade 5 students did not sacrifice the auditory task for the visual task when the visual task was high priority and the auditory task was low priority.

A follow-up analysis of the difference scores between the high and low priority tasks yielded further support for the hypothesis. A significant main effect for Grade [$F(1, 44) = 16.59, p < .001$] was obtained on the difference score measure. The Scheffe means comparisons indicated that the mean difference score (i.e., high priority minus low priority) was significantly higher for the University students ($M = .23$) than for the Grade 5 students ($M = .03$) or the Grade 2 students ($M = -.04$). In addition, the Grade 8 students ($M = .14$) obtained higher difference scores than Grade 2 students ($M = -.04$). These Scheffe comparisons were significant at the .01 level:

**Hypothesis 3.** The third hypothesis predicted that the performance tradeoff during time-sharing would be greatest for the difficult version of the high priority task and that this effect of priority would be found to be significant for the adult subjects but not for the Grade 2 children.

Hypothesis 3 was supported by the significant Grade X Visual Task Difficulty X Payoff interaction on auditory task performance [$F(6, 80) = 4.73, p < .001$] (see Table 5). The
partial interaction of GRADE X PAYOFF when the visual task was easy was not significant ($F(6, 80) = .80$, $p > .10$) (see Figure 14), but the interaction between GRADE and PAYOFF was significant when the visual task was difficult ($F(6, 80) = 6.79$, $p < .001$) (see Figure 15). The payoff comparison (i.e., high versus low priority) by grade comparison (i.e., grades 2 and 5 versus grade 8 and university) was significant ($F(1, 44) = 16.03$, $p < .001$). An analysis of the simple effects of this interaction comparison indicated that the payoff comparison (high versus low priority) was not significant at the younger grades ($F(1, 22) = .00$, $p > .10$) but was highly significant at the older grades ($F(1, 22) = 27.20$, $p < .001$).

The University and the Grade 8 students performed significantly worse on the auditory memory task when the visual task was hard and was high priority (i.e., primary). Thus the difficulty manipulation of the primary task reduced the secondary task performance only for the older subjects (and not for the younger subjects) when the auditory task was secondary or low priority. However, the effect was not grade or age dependent when the low priority task was the visual task. The GRADE X ATD X PAYOFF interaction was not significant for the visual memory task performance (see Table 6) but the ATD X PAYOFF interaction was significant.
Figure 14: Mean percentage scores on the auditory memory task by grade level and task priority at the easy level of the visual task.
Figure 15: Mean percentage scores on the auditory memory task by grade level and task priority at the difficult level of the visual task.
$F(2, 80) = 7.23, p < .001$. Figure 16 displays this interaction effect.

Figure 16 suggests that the difficulty level of the high priority auditory task had a dramatic effect on the low priority visual task performance independent of Grade. The simple effects of payoff when the auditory task was easy was not significant ($F(2, 80) = .31, p > .10$), but the simple effect of payoff when the auditory task was difficult was significant ($F(2, 80) = 15.47, p < .001$). The simple effect of the payoff comparison (i.e., high versus low priority) was also significant at the difficult version of the auditory task ($F(1, 40) = 20.50, p < .001$). Thus, the results indicate that the difficult, high priority auditory task is protected at large cost to the low priority visual task at all ages. The difficult, high priority visual task is protected at a large cost to the low priority auditory task performance only in older subjects (Grade 9 and adults). The younger subjects (Grades 2 and 5) did not sacrifice performance on the low priority auditory task to protect the difficult/high-priority visual task.

A higher order interaction was obtained on visual memory task performance. The GRADE $\times$ ATD $\times$ VTD $\times$ PAYOFF interaction was moderately significant ($F(6, 80) = 2.90, p < .025$). Figures 17 through 20 present this interaction
Figure 16: Mean percentage scores on the visual memory task by task priority and difficulty level of the auditory task.
Figure 17: Mean percentage correct on the visual memory task by task priority and difficulty level of both tasks at the Grade 2 level.
Figure 18: Mean percentage correct on the visual memory task by task priority and difficulty level of both tasks at the Grade 5 level.
Figure 12: Mean percentage correct on the visual memory task by task priority and difficulty level of both tasks at the Grade 8 level.
Figure 20: Mean percentage correct on the visual memory task by task priority and difficulty level of both tasks at the Adult level.
effect separately for each grade level. The first notable observation is that the 4 combinations of task difficulty produce similar effects on visual task performance across grade. This is supported by the failure to obtain a significant GRADE X ATD X VTD interaction effect, or a significant GRADE X ATD or GRADE X VTD interaction effect on the visual performance measure (see Table 6). The lowest performance scores were obtained in the auditory-difficult plus visual-difficult combination, the next highest scores were obtained in the auditory-easy plus visual-difficult combination, the third highest scores were obtained in the auditory-difficult plus visual-easy combination, and the highest scores were obtained in the easy-auditory plus easy-visual combination. Also noteworthy is that the priority manipulation had virtually no effect upon visual task performance at any grade when the two tasks were easy.

This 4-way interaction was broken down into partial factorials in order to investigate the specific interactions between the age variable (GRADE) and the priority variable (PAYOFF). The diagram in Figure 21 presents the steps involved in this analysis. At Step 1, the 3-way interactions between GRADE, PAYOFF, and VISUAL TASK DIFFICULTY, were investigated at each level of AUDITORY TASK DIFFICULTY. Both of these 3-way interactions were significant (see Figure 21).
Figure 21: Steps involved in the analysis of the GRADE X PAYOFF X VTD X ATD Interaction.
Step 2 involved an analysis of the 2-way interactions between GRADE and PAYOFF at each combined level of auditory and visual task difficulty. The GRADE X PAYOFF interaction was not significant when both tasks were easy but was significant in the other three combinations of task difficulty (see Figure 21). Step 3 of these analyses involved an analysis of the simple effects of the priority manipulation at each grade level at each combined level of task difficulty for the significant GRADE X PAYOFF interactions obtained in Step 2.

The effects which contributed to the significant GRADE X PAYOFF interactions are identified by an asterisk in Figure 21. At the Grade 2 level, PAYOFF had a significant effect on visual task performance only when the visual task was hard and the auditory task was easy ($F(2, 20) = 3.66$, $p < .05$). At the Grade 5 and Grade 8 levels, PAYOFF had a significant effect ($F(2, 20) = 5.64$, $p < .025$ and $F(2, 20) = 6.42$, $p < .01$, respectively) on visual task performance only when both tasks were difficult. At the university level, the PAYOFF manipulation had a significant effect when either one or both tasks were difficult (see Figure 21).

The priority manipulation did produce an effect for the Grade 2 children when the visual task was difficult and the auditory task was easy, but this effect was counter-
productive and counter-intuitive. The Grade 2 children decreased their performance on the difficult visual task when the task had a higher payoff (see Figure 17). The Grade 5 children displayed the expected performance shift only when both tasks were difficult (i.e., the protection of the auditory high priority task had a significant cost to the visual low priority task only when both the visual and auditory tasks were difficult; see Figure 18). The Grade 8 students demonstrated the expected pattern of performance shifts in accordance with the priority manipulation when either one or both tasks were difficult (see Figure 19). In the difficult-auditory plus easy-visual condition, the decrease in performance from high priority to low priority was 14 points, within the easy-auditory, plus difficult-visual condition, the decrease in performance was 10 points, and when both tasks were difficult the decrease in performance was 36 points. However, only this last difference was statistically significant. Thus the cost to the visual task performance of protecting the high priority auditory task was significant only when both the auditory and visual tasks were difficult.

The adult sample displayed a similar pattern to the Grade 8 sample except that the performance decrements were large across conditions of difficulty. Thus the cost of
protecting the high priority auditory task was significant when either or both tasks were difficult (see Figure 20).

**Hypothesis 4.** The fourth hypothesis predicted that the efficiency in resource allocation (i.e., utility) would be dependent upon age. Thus, the performance tradeoff in the adult subjects was expected to produce higher total point scores than the performance tradeoff in the Grade 2 subjects.

A one-way ANOVA for Grade was performed on the total point score. The main effect for Grade was not significant ($F(3, 44) = 2.12$, $p > .10$). In fact, the mean point score for each grade indicated an opposite pattern to the expected results. The Grade 2 children obtained the highest point scores ($M = 125.67$) and the University students obtained the lowest point scores ($M = 108.00$). The difference between these means was not significant at the .05 level (Scheffe means comparisons test). Although the University students appeared to put significantly more effort into the high priority task than into the low priority task, the absolute dual-task performance of the Grade 2 children was higher and may have served to eradicate any differences between the grades on this utility measure.

A correlational analysis indicated that while the relationship between memory span and age was positive, the
relationship between memory span and memory task performance was negative. The Pearson product-moment correlations indicated that performance decreased on both memory tasks as memory span increased (see Table 7). Table 8 presents the mean number of items on each memory task by grade level and task difficulty. Variability was limited in the younger grades on the easier version of the tasks due to a floor effect. However, as Table 8 indicates, the mean number of items per task did increase as a function of age. An analysis of covariance was then conducted on the same total point score using auditory and visual memory span as the covariates. Although the main effect for Grade was not significant, the visual memory span covariate accounted for a significant portion of the variance on this total point score ($F(3, 42) = 12.64$, $p < .001$).

A separate analysis was carried out on the point scores within each of the 12 within subject conditions. This analysis indicated a significant main effect for PAYOFF ($F(2, 80) = 28.09$, $p < .001$). Scheffe mean comparisons indicated that the highest point scores were obtained when the auditory tasks was a high priority and the visual task was a low priority ($M = .77$). The next highest point scores were obtained when both tasks were of equal value ($M = .71$), and the lowest scores were obtained when the visual task was
Table 7

*Inter correlations Between Memory Span, Age, and Memory Task Performance*

<table>
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<tr>
<th></th>
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<th>AMS</th>
<th>Age</th>
<th>ATS</th>
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<td></td>
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<tr>
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<td>.676 ***</td>
<td></td>
<td></td>
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<td>-.255 ***</td>
<td>-.200 ***</td>
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<td>VTS</td>
<td>-.197 ***</td>
<td>-.129 **</td>
<td>-.052</td>
<td>.128 **</td>
</tr>
</tbody>
</table>

*Note.* VMS = Visual Memory Span, AMS = Auditory Memory Span, VTS = Visual Task Scores, ATS = Auditory Task Scores.

** p < .01  
*** p < .0001
Table 8

Means and Standard Deviations for the Number of Items per Task by Task Difficulty Level and Grade.

<table>
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<th>Grade</th>
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<th>5</th>
<th>8</th>
<th>U*</th>
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<td>(.00)</td>
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<td>Hard</td>
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<td>3.67</td>
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<td></td>
<td></td>
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<td>(.65)</td>
<td>(.49)</td>
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<tr>
<td></td>
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<td>(.39)</td>
<td>(.65)</td>
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<td>Hard</td>
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<td>4.08</td>
<td>4.67</td>
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<tr>
<td></td>
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<td>(.67)</td>
<td>(.51)</td>
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</table>

*U* = University students.
a high priority and the auditory task was a low priority ($\bar{Y} = .63$). All three mean comparisons were significantly different at the .01 level (Scheffe mean comparisons test). Analysis of the interaction effects uncovered significant interactions for ATD X PAYOFF and VTD X PAYOFF.

The interaction between ATD and PAYOFF ($F(2, 80) = 6.70$, $p < .01$) is presented in Figure 22 and the interaction between VTD and PAYOFF ($F(2, 80) = 33.91$, $p < .001$) is presented in Figure 23. An analysis of the simple effects of the priority manipulation at each level of difficulty was completed. The simple effect of payoff when the auditory task was easy was highly significant ($F(2, 80) = 45.53$, $p < .001$) and, when the auditory task was difficult, was marginally significant ($F(2, 80) = 3.26$, $p < .05$). The simple effects of PAYOFF when the visual task was easy was not significant ($F(2, 80) = .44$, $p > .10$) but when the visual task was difficult, was highly significant ($F(2, 80) = 63.65$, $p < .001$).

As Figure 22 demonstrates, the priority manipulation had a larger effect on utility when the auditory task was easy and a somewhat lesser effect on utility when the auditory task was difficult. Figure 23 indicates that
Figure 22: Mean percentage scores on the utility point-score measure by task priority and difficulty level of the auditory task.
Figure 23: Mean percentage scores on the utility point-score measure by task priority and difficulty level of the visual task.
utility is not differentially affected by the priority manipulation when the visual task is easy, but is largely affected by payoff when the visual task is difficult. In summary, "utility", defined as the best distribution of resources to maintain optimal performance levels, is affected by which task is the high priority task (i.e., auditory or visual). When the high priority task is the auditory task, utility scores are high. This effect occurs whether the auditory task is easy or hard but is largest when the auditory task is easy. In addition, this effect is not apparent when the visual task is easy, but only when the visual task is hard.
CHAPTER IV
DISCUSSION

The first section of this chapter presents a general discussion of the Resource Theory predictions. These predictions were based upon the tenants of the multiple-resource model as proposed by Navon and Gopher (1979) and Wickens (1984). The second section of this chapter addresses the specific developmental predictions which were based upon the research conducted by Lippa Birch (1976, 1978) and Lane (1979). A general conclusion concerning the ability of this model to accommodate developmental findings is presented. In the final section, some possible directions for future research and educational implications are discussed.

Predictions_from_Resource_Theory

Single-to-Dual Task Decrement. Resource theory predicts that if two time-shared tasks draw from overlapping resource pools, and if they cannot be integrated into a unified single task, then the two tasks will be time-shared at some cost to the performance level of one or both tasks.
(Wickens, 1984). The more resources which are common to and shared by the two tasks, the larger this decrement is expected to be. In addition, when the task demands increase in a manner which increases the demand on common resources, the cost of concurrence is expected to increase (Navon & Gopher, 1979).

As expected, subjects in the present study showed a significant performance decrease from the single task condition to the dual task condition. Despite the fact that the study was designed to avoid channel/modality constraints through use of different input modalities (i.e., auditory and visual) and different response modalities (i.e., vocal and manual), the two tasks were not perfectly time-shared. This cost of concurrence suggests that the two tasks do share some common overlapping resources which are not specific to either input or output modality. In Wickens (1984) model, the overlap in resources could have occurred at the level of input or throughput codes and/or at the highest level of the hierarchy (i.e., undifferentiated resources).

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There were two notable exceptions where time-sharing performance was perfect or nearly perfect. In both cases these were Grade 2 children who appeared to be at a stage in memory development somewhere between their criterion performance and the next higher level of achievement. In each case the time-sharing condition did not appear to be difficult enough to cause interference even when the time-shared tasks were both difficult.
**Difficulty Manipulations.** In the present study, the single-to-dual task decrement was larger when the difficult versions of the tasks were time-shared than when the easier versions of the tasks were time-shared. This finding also supports the Resource Theory conceptualization of attention. As expected, the difficulty manipulation had the effect of increasing the dual-task interference (i.e., the demand on shared resources), producing larger performance decrements when the task was more difficult. However, a task-specific effect was also obtained. It was found that auditory task performance was not affected by changes in visual task difficulty, but that visual task performance was affected by changes in auditory task difficulty. This finding suggests that there was a bias toward protecting the auditory task when each task was of equal priority or value.

**Performance Tradeoffs.** Resource theory predicts that the high priority task will be maintained at a higher level than the low priority task if the two tasks cannot be perfectly time-shared. Support was obtained for this resource theory prediction only in the older age groups. Only the Grade 8 and University students performed differentially better on the high priority task than on the low priority task. This finding was consistent with the developmental predictions delineated in the first chapter.
Demand Composition. Resource theory predicts that the difficult version of the primary task will produce a greater reduction in secondary task performance than the easier version of the primary task. If the two tasks draw from at least some of the same limited resource pools, and the primary task increases in difficulty such that the demand on shared resources increases, the increased demand should result in a higher cost to the secondary task. In the present study, the difficult level of the each task was set at a maximum performance level under the single task condition. Performance is considered data limited beyond the criterion performance level. The added demand upon a common resource pool imposed by the time-sharing should result in a cost to one or both tasks because the combined demand on resources (r) will exceed the limit on resources (R1). If both tasks cannot be performed at 100% accuracy, Resource Theory predicts that it is the secondary or low priority task that will be sacrificed. Support was obtained for this Resource Theory prediction; however, task specific (or modality) effects were also obtained.

When the visual task was secondary or low priority, visual task performance was sacrificed to protect the primary auditory task, but only when the primary auditory task was difficult, not when it was easy. This tendency to
protect the difficult high priority auditory task by sacrificing visual task performance was observed across age.

When the auditory task was secondary or low priority, auditory task performance was sacrificed to protect the primary visual task when that primary visual task was difficult, but this effect was age dependent. Only the older subjects (i.e., Grade 8 and University students) demonstrated a tendency to protect the difficult high priority visual task by sacrificing auditory task performance. Thus, a modality effect and/or the task demands of each task produced differential performance in the younger and older subjects. This age effect cannot be accounted for by a difference in the absolute performance levels between the younger and older subjects, as the older subjects outperformed the younger subjects on the visual memory task when that task was both high priority and difficult.

**Utility.** Resource theory predicts that the system will strive toward the most efficient tradeoff of resources that will maximize payoff. The most efficient tradeoff of resources when the two tasks cannot be perfectly time-shared should devote proportionally more resources to the higher paying task in order to maximize performance on that task. However, the analysis of the utility scores within the 12
time-shared conditions indicated that utility was dependent upon not only auditory and visual task difficulty, but also upon which task was the high priority task. Utility or processing efficiency was highest when the auditory task was high priority and lowest when the visual task was high priority. The most parsimonious explanation of these findings is that the demand composition of the two tasks placed different demands on shared resources.

**Variable Proportion Functions.** The multiple-resource model suggests that the tradeoff of resources can be quite complex. The utility increase resulting from changes in the subjective substitution rate between the two tasks will depend upon the demand composition of each task. A shared resource pool may be utilized in differing proportions by the two tasks. For example, releasing one unit of the visual-auditory resource from the auditory task to give to the visual task may be quite ineffective if the demand composition of the visual task requires 5 units of this shared resource to affect any performance changes. However, releasing one unit of the shared resource from the visual task to give to the auditory task may be very effective in increasing utility.

In the present study, if the productivity of a unit of shared resource is higher for the auditory task than for the
visual task, then utility would be expected to be higher when resources were shifted from the visual task to the auditory task than when resources were shifted from the auditory task to the visual task. This assumption concerning the productivity of a unit of shared resources is supported by the phenomenological reports of many subjects who indicated that the visual task was more difficult (in theoretical terms, more resource demanding) than the auditory task. In addition, an information processing analysis of the task demands of each task would also indicate that the novel visual stimuli would be more difficult to encode, store, and retrieve than the more familiar and meaningful auditory stimuli.

**Developmental Predictions**

In a review of the developmental literature on information processing limitations, Wickens (1974) concluded that developmental limitations on central processing become apparent when more than one stimulus is presented and more than one response is required. Accordingly, Lipps Birch (1976) presented an auditory matching task and a visual tracking task concurrently to 7, 10, and 13 year old children to assess developmental differences in time-sharing ability. Lipps Birch found that the younger children
obtained significantly larger single-to-dual task decrement scores than the older children. However, she also observed that the initial baseline error scores were significantly higher for the younger children. In a second study Lipps Birch (1978) found no differences in decrement scores when younger and older children were equated on baseline task performance.

In the present study, single task performance was equated at baseline by setting the difficulty level of each task for each individual subject at a criterion level. As expected, all subjects demonstrated a single-to-dual task decrement in task performance. No significant age differences were found in the size of the single-to-dual task decrement. This finding, along with the findings of Lipps Birch, suggests that children do not experience greater dual-task interference than adults if the children are as proficient as the adults on the tasks before the time-sharing trials begin. Research conducted in the area of memory processing has led to similar conclusions concerning the effect of prior knowledge or experience on information processing efficiency.

Bjorklund (1987) has suggested that it is the increased familiarity with the items used on short term memory tasks that is largely responsible for the developmental increases in memory span commonly found in memory research studies.
Bjorklund states that an item in semantic memory develops a lower threshold for activation in certain contexts due to repeated exposure to and subsequent activation of that item. Repeated experiences with a semantic memory unit may include either directly experiencing the meaningful item or merely exposure to the item's linguistic counterpart (i.e., verbal label).

In summary, it appears that the efficiency of information processing is heavily dependent upon prior experiences and prior knowledge. If it is possible to eliminate developmental differences in the experiential and procedural knowledge base, then the information processing system of the seven-year-old suffers no additional cost of concurrence in comparison to the adult. These findings support an automatization hypothesis as an explanation of cognitive developmental change, but do not directly address the growth hypothesis.

**Developmental Limitations on Information Processing**

Past research concerning the age at which children can establish sufficient attentional control to allocate resources differentially to a higher priority task has been inconclusive. Lipps Birch (1976) found that even her youngest age group (i.e., 7-year-olds) could differentially allocate resources to the primary task. However, Lane
(1979), using a more controlled design, found that none of the 7 year old group and only about half of the 9 year old group could differentially allocate resources to the higher paying task.

The degree of attentional control is assessed by establishing one task as having priority over the other time-shared task. A major problem in this type of research is controlling for developmental differences in children's ability to respond to the verbal instructions about task priorities (Wickens, 1974). Every effort was made in the present study to reduce the language skill requirements of the verbal instructions for the 7 year old children. In addition, the verbal instructions were supplemented by visual cues (i.e., tokens) which differed in colour for each task and were placed beside the symbol board and the tape recorder according to the payoff schedule. Following each trial the child received the tokens beside the task(s) recalled correctly.

In the present study, neither of the two younger age groups demonstrated differential performance favoring the higher paying task. Only the older subjects (i.e., Grade 8 and University students) demonstrated the expected performance changes when priority changed. The adults (average age 21.92 years) obtained the largest differential
performance followed closely by the Grade 8 students (average age 13.80 years). The Grade 5 students (average age 10.84 years) demonstrated a small but insignificant differential performance between the high and low priority tasks. The Grade 2 students (average age 7.87 years) demonstrated an opposite pattern of performance, obtaining higher scores on the lower priority task than on the higher priority task. This pattern for the Grade 2 students was apparent only when the visual task was high priority. Task specific effects were obtained only in the younger age groups (i.e., Grades 2 and 5).

The Grade 2 and Grade 5 students did not sacrifice auditory task performance regardless of which task was higher paying. The mean performance level on the auditory task was maintained across payoff conditions in both younger age groups. However, the two groups did not perform similarly on the visual memory task. The Grade 2 students demonstrated a performance decrement when the visual task was a high priority. This decline in performance requires some explanation.

**Memory Processing Strategies.** The use of processing strategies (e.g., labeling, chunking, rehearsing) typically has the effect of freeing up attentional resources to be used elsewhere in the system (Kail & Bisanz, 1982). However, the implementation of a cognitive strategy is often
very resource demanding for children who have less practice at using the strategy (Guttentag, 1984; Bjorkland and Harnisheqer, 1987). Younger children typically have fewer strategies and less practice at implementing strategies than older children. Thus young children would be expected to suffer a greater cost if they were trying to implement a strategy to allocate attention and to improve memory performance. For the Grade 2 children, this cost of allocating attention to the higher paying task appeared to exceed the limits of resources available to be used by the visual task under time-sharing conditions. Alternatively, trying too hard on the visual task may have led to an increase in arousal level which interfered with performance. The Yerkes-Dodson law, which describes the inverted "U" shaped function relating arousal to performance, predicts that trying too hard may result in a performance decrement if increased effort leads to increased arousal. This effect is more likely to occur if the task is complex (Easterbrook, 1959).

These developmental limitations also extended to the performance tradeoff effects on secondary task performance when the primary task was difficult. All subjects protected the primary auditory task at a cost to the visual task when the auditory task was difficult. However, only Grade 8 and
University subjects protected the primary visual task when it was difficult. Three possible explanations are proposed to explain this phenomenon.

**Perceptual Bias Hypothesis.** Shaffer (1985) states that sensory dominance over perception changes from childhood to adulthood. Auditory input appears to dominate the perceptions of young children (McGurk & MacDonald, 1976), whereas visual input appears to dominate the perceptions of adults (Gibson, 1933; Rock & Victor, 1964; Klein & Posner, 1974). McGurk and MacDonald (1976) presented inconsistent auditory and visual inputs to preschool-age children and adults. The results indicated that both groups were more accurate in reporting the sounds when the sounds and visual cues matched, but that the children were more accurate than the adults when the sounds and the visual cues were inconsistent. Thus adults appeared to be attuned to what they saw, whereas children appeared to be more attuned to what they heard. Shaffer states that adults have learned to put more faith in what they see than what they hear whenever the two modalities provide conflicting input.

**Visual Maturation Hypothesis.** Several studies suggest that the ability to allocate attention in the visual field undergoes dramatic developmental change sometime around the
onset of puberty. Hägen (1967) presented a visual learning task to 7, 9, 11, and 13 year old children in the presence of auditory distractions (i.e., piano notes). The results indicated the auditory distraction made visual learning more difficult but affected the younger children (ages 7 and 9) more than the older children (ages 11 and 13). Similarly, Schrief and Knopf (1985) found that 9 year olds had significantly more difficulty allocating visual attention to a particular aspect of the visual field than 13 year olds. The present study also found a significant change in the ability to allocate attention to the visual task between 10 and 13 years. The consistency of this developmental finding suggests the possibility that attentional deployment skills are tied to the maturation of the nervous system (i.e., the process myelination within the reticular activating system).

Pathway Activation Hypothesis. Perhaps there is no modality bias in the performance of the young children but rather an information processing bias toward less costly, more resource efficient types of processing. The experimental tasks differed not only in terms of modality of input, but also in terms of familiarity, meaningfulness, and accessibility to stored memory codes. The words were familiar and were probably more easily activated by the
auditory input than the visual stimuli which would not have a well established, familiar code in memory (Posner & Snyder, 1975; Bjorklund, 1987). As a result, the auditory task was probably less resource demanding or more automatically activated than the visual task due to prior learning (Shiffrin & Schneider, 1977) or an inherent automatic processing bias toward word meanings (Hasher & Zacks, 1973). From a developmental perspective then, the ability to shift attention away from an automatically activated input to a more controlled and effortful type of processing, is somehow developmentally limited.

It is likely that all three of these biasing factors have played a role in the obtained findings. The auditory task was less resource demanding, and was more automatically activated by the input items. Young children could not reallocate resources to overcome both a perceptual bias and the automatic pathway activation set into effect by the familiar input. This ability to reallocate attention appears to be linked to limitations imposed by maturational processes.

Specificity of Effects. The higher order interaction obtained in the analysis of age, priority, and difficulty level factors indicated the specificity of the obtained results on the visual memory task. For example, the Grade 2
children performed worse on the high priority visual task only when that task was difficult (i.e., when there were relatively more symbols to remember). The specificity of this finding suggests that the increased memory load requirement may have necessitated the use of some strategic action which was too resource demanding to be effective or that increased effort expenditure induced increases in arousal level which the Grade 2 children could not modulate as well as the older children. Secondly, the Grade 5 children sacrificed visual task performance to protect auditory task performance only when both time-shared tasks were difficult. In this case, it was the combined demand on shared resources that resulted in a reallocation of resources away from the visual task to protect the primary auditory task. The Grade 3 and University students demonstrated differential performance on the high and low paying visual task in all but the easiest time-shared conditions. However, this differential performance was significant for the Grade 3 students only when both time-shared tasks were difficult.

In summary, there are apparent developmental differences in children's ability to allocate attention to a resource-demanding visual task if that task is competing with a less resource-demanding auditory task. A change
occurs somewhere around the onset of puberty (i.e., between 10 and 13 years) which allows children to allocate attention more freely across modality and type of task to maximize payoff or reward.

The developmental findings in the present study differ somewhat from Lane's (1979) findings in the age of acquisition of attentional deployment skills. Lane found that a shift occurs somewhere around 9 to 10 years of age in children's ability to allocate attention differentially according to priority manipulation. One major difference between the two studies lies in the counterbalancing of the payoff conditions which may impose different demands upon the processing system. In Lane's (1979) study half of the subjects in each grade experienced one payoff condition (i.e., the auditory task pays 4 points and the visual task pays 1 point) in the in the first session and the other payoff condition (i.e., the auditory task pays 1 point and the visual task pays 4 points) in the second session. The other half of the subjects in each grade experienced the payoff manipulation in the opposite order of presentation. The difference between this methodology and the present one lies in the fact that the children were responding to the same priority or payoff for 24 continuous trials over a 30 to 40 minute period, providing ample opportunity for a
cognitive strategy to develop in the face of continued failure to accumulate points. Given the opportunity for sufficient practice at one level of payoff in Lane's study and the added difficulty of the visual task in the present study, the differences in the developmental findings may reflect both practice and novelty effects. Lane's finding may reflect the fact that some children around age 9 or 10 are capable of implementing their own strategies for selective attention when given sufficient opportunity or practice at a task. This skill may depend upon previous experience or practice (e.g., the need to ignore a talkative child who sits next to you in the classroom). In addition, the novelty and complexity of the visual memory task in the present study may have imposed a heavier demand upon the processing system thus drawing upon resources which otherwise could have been used to implement an allocation strategy.

The final developmental prediction, concerning the utility of the performance tradeoff, was not supported. The utility of the performance tradeoff was expected to be significantly less in the Grade 2 group than in the adult group. This prediction was based upon the research by Lane (1979) which suggests that younger children are less efficient at allocating resources to the higher paying task.
A correlational analysis indicated a significant negative correlation between memory span and task performance and a significant positive correlation between memory span and age. It appears that the number of items a person can hold in memory may be a mediating variable which obscures developmental changes in utility.

The developmental literature suggests that developmental increases in memory span reflect developmental changes in the choice of processing strategies and their ease of implementation (Shaffer, 1985). If this is the case, then we can expect that the demand composition of the memory tasks will change, both in terms of proportion and type of resource, as memory span increases. For example, the demand imposed upon the system in trying to recall 2 items at 7 years of age may not be the same as the demand imposed by trying to recall 7 items at 20 years of age, even if both levels are maximum performance levels for individual subjects. The demand imposed upon the system by these two levels of the task may differ because the older subject is using some strategy for remembering (e.g., rehearsal, chunking, etc.) which changes the demand composition of the task.

This effect is exemplified by the differences in the mixed difficulty conditions between the Grade 3 and
University students on the visual memory task. The fact that Grade 8 students did not have to sacrifice as much of the visual task to protect the auditory task when one task was difficult and the other easy, may be explained by the fact that the average number of items which had to be recalled was less for the Grade 8 subjects than for the University subjects. Interestingly, those University students who could recall between 6 and 8 items on the memory tasks under single task conditions, performed very poorly under time-sharing conditions. Many of these students with long memory spans could not accurately time-share even the easier versions of the tasks (i.e., two levels below their criterion performance), presumably because the strategy they selected to use was too resource demanding when implemented under time-sharing conditions.

In summary, the amount of shared resources appears to increase as a function of the number of items which must be recalled. As the number of items to be recalled also increases with age, the dual-task interference was somewhat larger for adults than for children. This mediating effect probably obscured the age differences which were expected on the utility measure.
General Conclusions

The hierarchical model of multiple resources as proposed by Wickens (1984) has received general support. The model must, however, address some important developmental differences between adults and children in terms of how the system processes information. The model appears to be versatile enough to accommodate the findings obtained in the present research. The findings support the concept of limited processing capacity as the two tasks could not be perfectly time-shared. The results also support the concept of higher order capacity limitations which are not specific to input or output modality. Wickens (1990) refers to these limitations as a nonstructural commodity labeled attention or effort. These processing limitations are common to all human information processing systems regardless of developmental or maturational level.

When the system is overtaxed, such as when two tasks compete for the same limited resources, the adult processing system has an advantage over the less well developed processing system of the child. Adults can differentially allocate attentional resources to a high priority task, demonstrating more attentional control than young children. Developmentally, this control over attention shows dramatic increase between 10 and 13 years. Younger children do not
exhibit this control for one or more possible reasons. First, they may have to overcome inherent perceptual biases. Secondly, they may not be maturationally prepared to allocate attention differentially because of limitations in the central nervous system. Finally, younger children may be operating on an information processing bias which seeks less resource demanding types of tasks.

It is clear that the young child does not process information in the same way that adults do. One important difference is in the use of information processing strategies. These strategies, along with increases in the knowledge base, and reorganization within the knowledge base, lead to increases in the efficiency of the system, but in so doing, appear to qualitatively change the way in which the system approaches a task. Thus, equating performance at different ages will not necessarily equate the task demands placed upon the system.

Implications for Future Research

Researchers interested in effortful processing in childhood may wish to consider the use of the dual-task paradigm as a valuable tool for assessment of capacity limitations. At the same time, researchers should be cautious when attempting to equate performance levels
between age groups, as making the task more difficult can also change the task qualitatively. The results of the present study suggest several modifications to the research paradigm which could more clearly delineate the nature of the processing limitations in young children.

[1] The present study suggested that an important developmental change occurs sometime around the onset of puberty, in children's ability to exercise control over resource allocation. However, the study did not provide conclusive answers to why young children consistently favored the auditory task. If the items on the auditory task were more readily activated by the familiar input, then perhaps it is not a channel bias, but a task-specific effect which was observed. If the auditory task could be equated with the visual task for the absence of stored memory codes (e.g., if nonsense syllables were used instead of words), more conclusive explanations of the observed effects would be possible.

[2] The addition of a metamemory measure to assess or manipulate the child's knowledge and awareness of how memory can be facilitated could provide information concerning the effect of processing strategies on task performance. It would be interesting, for example, to ask the children to estimate how much energy or effort they devoted to each task under different payoff conditions. It might also be
interesting to examine whether making the children aware of capacity limitations in this way has any affect upon task performance. Cole and Newcomb (1983) found that even 7 year old children could increase performance on a selective attention task when they were instructed to pretend that there was a door that they could close between themselves and an auditory distraction. This type of instruction concerning the effective use of cognitive mediating strategies may be useful in helping young children to allocate attention more efficiently.

[3] As the present research uncovered some evidence of a developmental change corresponding to a rapid period of physiological growth, a longitudinal research project which addresses individual changes in attentional control could provide valuable information concerning related causal factors. This type of research could provide some important insights into the information processing capabilities of the emerging adult (i.e., the ability to entertain many hypotheses simultaneously, the ability to direct and control attention, and the ability to reason logically given abstract premises).
Educational Implications

The present study has pointed to several developmental limitations on the school-aged child's ability to exercise attentional control. It is important for teachers and others who work with young children to be aware of the processing demands imposed upon children when introducing novel information, particularly if that information is introduced in the presence of auditory distractions. Auditory distractions can be quite disruptive to visually oriented tasks that are highly resource demanding or involve multiple steps (e.g., seat work in mathematics, completing problem solving tasks, memorization, classification, etc.). Any task that requires concentrated effort will impose a high demand upon the child's limited resources. Even when very young children attempt to establish voluntary control over allocation of attention, their efforts will often not meet with success if competing stimuli are intruding which have more automatic control over the resource allocation policy of the system. Young children are easily distracted by the salient aspects of their environment. Salient input, by definition, has a lower threshold for activation in the nervous system. Therefore, lessons which introduce new concepts should be introduced in an atmosphere which is free from distracting influences which could literally pull the
child's attention away from the task at hand. These developmental limitations on information processing appear to have a biological base and are overcome sometime during late childhood or early adolescence.
REFERENCES


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Appendix A

PARENT_PERMISSION_FORM_A

GRADES 2 AND 5

Dear Parent(s)/Guardian(s):

I am requesting permission for your son/daughter to participate in a study of memory and attention that I am conducting in your child's school. The aim of the study is to gain a better understanding of the way children at different ages divide their attention between two tasks that are occurring at the same time. This research has implications for understanding how children at different ages learn. As we know, children learn by both listening and watching. Their everyday experiences in the classroom require them to avoid paying attention to some things (such as ignoring distractions while studying), as well as to divide their attention between relevant events happening at the same time (such as listening to the teacher while copying from the blackboard). I am studying how well children at different ages can filter out distractions and divide their attention between relevant events.
The study will involve having the children do two memory tasks alone and then together with different incentives to give more attention to one task or the other. As such I hope to gain some understanding of how much control children have over how they allocate their attention. Each student will earn tokens for accurate performance. The children will be individually assessed to set an appropriate level of difficulty for the tasks so that successes occur frequently. The study will be completed during school hours at the school and will take approximately one hour spread over 2 separate days. The game-like quality of the tasks makes the tasks appealing to the children. At the end of the study the children will have a chance to exchange their tokens for a small prize (e.g., a pencil, an eraser, stickers, etc.).

This study is being completed in partial fulfillment of the requirements for my Ph.D. degree in Developmental Psychology at the University of Windsor. Should you have any questions about the study please feel free to contact me through the Psychology Department of the University of Windsor (253-4232, Ext. 2218).

If you consent to your child's participation in this study please sign the consent form and return it to the school.
Appendix B

PARENT PERMISSION FORM B

GRADE 8 STUDENTS

Dear Parent(s)/Guardian(s):

I am requesting permission for your son/daughter to participate in a study of memory and attention that I am conducting in your child's school. The aim of the study is to gain a better understanding of the way students at different ages divide their attention between two tasks that are occurring at the same time. This research has implications for understanding how students at different ages learn. As we know, children learn by both listening and watching. Their everyday experiences in the classroom require them to avoid paying attention to some things (such as ignoring distractions while studying), as well as to divide their attention between relevant events happening at the same time (such as listening to the teacher while copying from the blackboard). I am studying how well children at different ages can filter out distractions and divide their attention between relevant events.
The study will involve having the students do two memory tasks alone and then together with different incentives to give more attention to one task or the other. As such I hope to gain some understanding of how much control the students have over the way they allocate their attention. Each student will earn points for accurate performance. The students will be individually assessed to set an appropriate level of difficulty for the tasks so that successes occur frequently. The study will be completed during school hours, and will take approximately one hour spread over 2 separate days. At the end of the study the students will be able to trade in their points for a monetary reward (i.e., one cent per point). Each student will receive between two and three dollars for their points.

This study is being completed in partial fulfillment of the requirements for my Ph.D. degree in Developmental Psychology at the University of Windsor. Should you have any questions about the study please feel free to contact me through the Psychology Department of the University of Windsor (253-4232, Ext. 2218).

If you consent to your child's participation in this study please sign the consent form and return it to the school.
Appendix C

TEACHER'S_SELECTION_CRITERIA

Dear Classroom Teacher:

I would like to request you assistance in selecting students to participate in my study. I will require 12 students from each of the grades 2, 5, and 8 to participate. The students will be seen individually for approximately 1 1/2-hour sessions spread over 2 separate days. I am including a copy of my research proposal for your perusal. Please choose 12 students from your class to participate. The students selected should not have: (1) identified learning problems (past or present), (2) attentional or behavioural problems, (3) hearing or vision impairments, or (4) known brain injury. This selection procedure should ensure that the children who complete the study are normally achieving and normally developing children. Identified Gifted children should also be excluded since the purpose of this study is to evaluate attentional skills in normally developing children. Please have the children you select take home the parent consent form for their parents to sign. Thank You for your assistance.

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Appendix D

INSTRUCTIONS FOR GRADE 2 AND GRADE 5 STUDENTS

Session 1

Initial Introduction. I am interested in seeing how well kids can remember things and how well kids can play two different memory games at the same time. One game is called the Word game and the other game is called the Picture game.

Step 1. These are the words that you will hear in the Word game: cat, pine, lake, snow, chair, head, door, fork, doll, shirt, corn, and bus (show the drawings which depict the words as you say them). Now I will say them again so that you have a chance to become familiar with them (repeat the stimulus words with drawings as before). These are the pictures that you will see in the Picture game. Each picture is different (slowly point to the first few designs to focus the child's attention). Here are the same pictures all mixed up (point to the plastic chips). Can you find one here (point to the chips) that is just like this (point to the first symbol on the card). Good! (Place the chip under
the symbol.) Now find one just like this (point to the second symbol on the card). (Continue with the entire card.) Here is a card with only some of the pictures on it. See if you can find the pictures to match them. Start here (point to the first symbol in the sequence) and continue across (sweep finger across the card). Good now you are getting the idea. Here is another card (etc. as is needed). (Correct any mistakes the child makes.) O.K. good. Now you know what the pictures look like and how to match them to the card.

Step 2. Before we begin the game, I need to find out how many things you can remember. First we will begin with the words. Listen carefully to the taperecorder for the list of words to be remembered. First you will hear a jingle and then the words will come. You need to tell me the words back just like in a Simon Says game. The words must be in the same order in which you heard them. Do you understand? Let's try an example, say these words after me: cat, door (wait for response) O.K. good. (If the child does not understand, provide more examples as is necessary). Remember to wait until I say begin before you start to answer. Then you can tell me the words. O.K. are you ready? Let's start. (Testing will begin at the 2 word level for grade 2 children and at the 3 word level for the
grade 5 children. Testing will stop at the level at which 3 out of 4 or 3 consecutive items are failed.)

Now I will see how many of the pictures you can remember. You must try to remember the pictures I will show you on the card and then choose the same ones from here (point to the row of chips) and place here (point to the sheet taped to the table) in the same order in which you saw them on the card. For example, if I showed you these two pictures (show the example card) and then took the card away, you would choose this one to go here (place the correct chip in the first position) and this one to go here (place the second chip in the second place. Show the child the card again to make the instructions clear.) Do you understand what you have to do? O.K. let's begin.

(Following each trial, the symbols must be replaced on the board in a mixed up order.) (Testing begins at the 1 (or 2 for grade 5) symbol level and continues until 3 out of 4 or 3 consecutive items are failed. The challenging version of each task is set at the criterion level of 3 out of 4 correct and the easy version of each task is set at two levels below the criterion.)

Step 3. Now that you have had some practice at doing each of the games, you can earn some tokens for doing each game. These tokens can be used to buy a prize the next time
we meet. Each time you get a string of words correct, I will put one token in the pot beside you. If you do not get a token on some trials don't worry about it, because there will be more chances later on to earn tokens. (The easy and challenging versions of the task will be administered.)

Now you can earn tokens for remembering the pictures. Just like before with the words, you will earn one token for each row of pictures you remember correctly. Let's see how many you can remember. (The easy and challenging versions of the task will be administered.)

Step 4. O.K. you have been doing a fine job doing the games. Now I will give you a chance to practice doing both games at the same time. These are just for practice, but you should try your best so that next time we meet you can earn more tokens for doing both games together. I want you to listen to the words and to look at the pictures on the cards at the same time. This time I will be reading the words. I will show the card with the pictures for 5 seconds and then I will take it away. You should not do or say anything until I say begin. When I say begin, you should give your answers to both memory games. You can choose which ever answer you want to give first, either the words or the pictures. Try to get as many as you can correct because next time you will be earning tokens for each one you get correct.
At the end of the first session, the number of tokens the child has earned was recorded and the child was given verbal reinforcement. All responses, both verbal and visual task choices, were recorded on the appropriate answer sheet. The tokens were given for each success immediately following the response. The child could check his/her own visual choices when the examiner displayed the card again. The examiner provided the feedback on the verbal responses. Incorrect responses were handled casually (for example, "you just missed one or two words that time, let's try the next one"). On the dual-task practice trials easy and difficult trials were alternated so that a negative set would not develop. One trial in each of the four possible combinations of difficulty was provided.

Session 2

Step 1. Today you can earn tokens for remembering the words and the pictures again. For each string of words you remember I will give you 1 token and for each row of pictures you get right I will give you 1 token, just like
last time. Do you think you can do as well today as you did last time? O.K. let's see. (Readminister the single-task words and symbols as in session one.)

**Step 2.** (Repeat the four dual-task practice trials without the reward as in session 1. Explain that these first four items are only for practice. Restate the dual-task instructions.)

**Step 3.** Today you can earn tokens for doing both games at the same time. The number of tokens I will give you for each correct answer will change throughout the games. Sometimes I will give you 2 tokens for remembering the words (place two tokens beside the tape recorder) and 2 tokens for remembering the pictures (place 2 tokens beside the symbols board). Sometimes I will give you 4 tokens for remembering the words (place four tokens beside the tape recorder) and 1 token for remembering the pictures (place one token beside the symbols board). And sometimes I will give you 1 token for remembering the words (place one token beside the tape recorder) and 4 tokens for remembering the pictures (place four tokens beside the symbols board). You should try to get the most tokens you can get each time. Each time I will tell you how many tokens you can earn for each correct answer. You must decide how to do the two games the best so
that you get as many tokens as possible. (Put the tokens beside the tape recorder and symbol board on each trial.) Try to remember both the words and the symbols the best that you can and MOST IMPORTANTLY try to get the most tokens you can. After each trial I will put the tokens you earn into the pot beside you. Do you understand the games now? When we are finished today, I will give you a choice of some prizes that you can buy with the plastic tokens you have earned.

Just like before, you will hear a bell jingle on the tape before the words come on. You will hear the words and at the same time I will show you the card with the pictures on it. I will show the card with the pictures on it for 5 seconds and then I will take it away, just like before. You should not do or say anything until I say begin. When I say begin, you should give your answers to both memory games. You can choose which ever answer you want to give first, either the words or the pictures or both at the same time.

Step 4. (The last step was to readminister the single-task condition as in step 1 to determine if performance was improved by practice.)
Each child was administered the 12 dual-task conditions in a predetermined counterbalanced order. At the end of the study, the child helped to count the number of tokens he/she earned and then chose a small prize from an assortment of pens, pencils, erasers, etc.
Appendix E

INSTRUCTIONS FOR GRADE 8 AND UNIVERSITY STUDENTS

Session 1

Introduction. This study is looking at memory and attention in students from grade 2 to university. Today I will be asking you to remember lists of words that you will hear on a tape recorder and rows of symbols that you will see in a booklet. There will be a second session to this study where you will be asked to do the two memory tasks at the same time. For each correct answer you give me I will give you one point. These points will be worth 2 cents each and will be tallied at the end of the study, at which time you will receive money for the points you have earned. Everyone will get a two-dollar minimum for their participation in this study. You can earn up to another two dollars for your efforts on the memory tasks.

Step 1. These are the words that you will hear in the word memory task: cat, book, lake, snow, chair, head, door, fork, doll, shirt, corn, and bus (give the student a copy of the word list to follow along). Now I will say them again.
so that you have a chance to become familiar with them
(repeat the stimulus words as before). These are the
symbols that you will see in the symbols memory task (show
matching card). Each symbol is different (slowly point to
the first few symbols on the card to focus the student's
attention). Here are the same symbols all mixed up (point
to the chips). Can you match each symbol to the card in the
same order? O.K. Good. Now can you match this row of
symbols to the card so that you become more familiar with
what they look like? O.K. Good. Now you know what the
symbols look like and how to match them to the card.

Step 2. Before we begin the tasks, I need to find out
how many things you can remember. First we will begin with
the words. Listen carefully to the tape recorder for the
list of words to be remembered. First you will hear a
jingle and then the words will come. You need to repeat the
words back in the same order in which you heard them on the
tape. Do you understand? Let's try an example, say these
words after me: cat, door, bus, chair. (wait for response)
O.K. It is important that you remember to wait until I say
begin before you start to answer (say begin after stimuli
are withdrawn). Then you can tell me the words. O.K. are
you ready? Let's start. (Testing will begin at the 4 word
level and will stop at the level at which 3 out of 4, or 3
consecutive items are failed.)
Now I want to see how many of the symbols you can remember. You must try to remember the symbols I will show you on the card and then choose the same ones from here (point to the row of chips) and place here (point to the sheet taped to the table) in the same order in which you saw them on the card. For example, if I showed you these three symbols (show the example card) and then took the card away, you would choose this one to go here (place the correct chip in the first position) and this one to go here (place the second chip in the second place) and this one to go here (place the third chip in the third place). (Show the student the card again to make the instructions clear.) Do you understand what you have to do? O.K. let's begin.

(Following each trial, the symbols must be replaced on the board in a mixed up order. Testing will begin at the 3 symbol level and will continue until 3 out of 4, or 3 consecutive items are failed. The challenging version of each task will be set at the criterion level of 3 out of 4 correct and the easy version of each task will be set at two levels below the criterion.)

Step 4. Now that you have had some practice at doing each of the tasks, you can earn some points for doing each one. Each time you get a string of words correct, I will check off one point on this point card. There will be times
when you will not get all the points but that is just part of the way the tasks are designed. I would like you to try your best and to do the best job that you can each time. (The easy and challenging versions of the task will be administered.)

Now you can earn tokens for remembering the symbols. Just like before with the words, you will earn one token for each row of symbols you remember correctly. Let's see how many you can remember this time. (The easy and challenging versions of the task will be administered.)

Step 5. O.K. you have been doing a fine job at each memory task. Now I will give you a chance to practice doing both tasks at the same time. These are just for practice, but you should try your best so that in the next session you can earn more points for doing both tasks together. I want you to listen to the words and to look at the pictures on the cards at the same time. This time I will read the words and place the card on the table at the same time. Just like before, I will show the card with the symbols for 5 seconds and then I will take it away. You should not do or say anything until I say begin (say begin after stimuli have been withdrawn). When I say begin, you should give your answers to both memory tasks. You can choose which ever answer you want to give first, either the words or the
symbols. Try to get as many as you can correct because next
time you will be earning points for each one you get
correct.

All responses, both verbal and visual task responses,
were recorded on the appropriate answer sheet. The
points were recorded on the point card immediately
after each correct response. Incorrect responses were
handled casually (for example, "you just missed one or
two words that time, let's try another one"). One
trial in each combination of task difficulty was
provided for the dual-task trials.

Session 2

Step 1. (The first step in this session was to
reacquaint the students with the stimuli. The 12 stimulus
words were read aloud again and the students matched the 8
symbols to the card again as in Step 1 of session 1.)

Step 2. Today you can earn points for remembering the
words and the symbols again. For each string of words you
remember I will give you 1 point and for each row of symbols
you get right I will give you 1 point, just like the last
time. (Readminister the single-task condition as in Step 3 of session 1.)

**Step 3.** (The dual-task practice trials are readministered as in Step 4 of the first session.)

**Step 4.** Today you can earn points for doing both tasks at the same time. The number of points I will give you for each correct answer will change throughout the tasks. Sometimes I will give you 2 points for remembering the words and 2 points for remembering the symbols. Sometimes I will give you 4 points for remembering the words and 1 point for remembering the symbols, and sometimes I will give you 1 point for remembering the words and 4 points for remembering the symbols. You should try to get as many points as you can each time. Each time I will tell you how many points you can earn for each correct answer. You must decide how to do the two tasks so that you can get the most points. Try to remember both the words and the symbols the best that you can but MOST IMPORTANTLY, try to get the most points you can. After each trial I will record the points you earn on the point card. Do you understand the tasks now? When we are finished today, I will count up the points and give you the money for them.
Just like before, you will hear a bell jingle on the tape before the words come on. You will hear the words and at the same time I will show you the card with the symbols on it. I will show the card with the symbols on it for 5 seconds and then I will take it away. When I say begin, you should give your answers to both memory tasks. You can choose which ever answer you want to give first, either the words or the symbols or both at the same time.

**Step 5.** (The single-task condition is readministered for the third time as in Step 3. This third administration is completed to assess the effects of practice.)

Each subject was administered the 12 dual-task conditions in a predetermined counterbalanced order. At the end of the study, the subject helped to count the number of points he/she earned and the points were exchanged for money.
Appendix F

SCORING PROCEDURES

Dual-Task Scoring Procedures

A score was calculated separately for the visual and auditory memory tasks for each of the 12 combinations of within subject variables (i.e., 2 levels of visual task difficulty X 2 levels of auditory task difficulty X 3 priority manipulations). A percentage score was calculated which reflected the number of exact judgements (i.e., the correct item recalled in the correct position; Penny, 1980) divided by the total number of possible exact judgements. These scores were then corrected for a position-practice effect by subtracting the mean score of each position (within grade) from the mean score of the total Latin square matrix for each grade. In addition, the total number of points earned within each of the 12 conditions was calculated as a percentage score. The percentage of total possible points earned within each condition is the measure of utility of the tradeoff of resources. These scores were corrected for the position-practice effect in the same manner as the visual and auditory task scores.
Single Task Scoring Procedures

The single-task condition was presented to the subjects on 3 separate occasions. Any increase in criterion performance from Time 1 to Time 2 was reflected in a change to a higher level of difficulty for the challenging and easier versions of the tasks. This increase in level of difficulty at Time 2 and subsequently for the dual-task conditions made the Time 1 performance uncomparable to the new difficulty level performance. As such only Time 2 and Time 3 (i.e., pre and post tests to the dual-task conditions) were used to obtain single-task performance levels for comparison with dual-task performance levels. In most cases, single tasks - both the easier and more difficult versions - were performed with 100% accuracy. When this was not the case, an average of Time 2 and Time 3 performance was calculated and this mean score was assigned as the single task performance for that individual. The single-task condition was given the same percentage score for exact judgements as the dual-task condition. The data from Time 1 of the single-task condition were dropped from the analyses.
Appendix G

ANALYSIS OF ORDER EFFECTS

A 12 ORDER (counterbalanced order of the 12 within-subject conditions) X 2 ATD (Auditory Task Difficulty - easy versus hard) X 2 VTD (Visual Task Difficulty - easy versus hard) X 3 PAYOFF (high, low, or equal) ANOVA was performed separately on the visual and auditory measures. The main effect for ORDER was not significant on the visual performance measure ($F(11, 36) = .43, p > .10$) or on the auditory performance measure ($F(11, 36) = .76, p > .10$). None of the interaction effects were significant (see Tables 9 and 10). The GRADE X ORDER interaction could not be assessed as only one subject served in each order within each grade.

These preliminary analyses indicate that the order of presentation of the within-subject conditions did not significantly contribute to the variance attributed to the difficulty or priority manipulations on either dependent measure.
Table 9

Analysis of Variance Summary Table for the ORDER X ATD X VTD X PAYOFF Analysis on Auditory Task Performance

| SOURCE               | df Effect | ANOVA SS | df Error |  |  |  |  
|----------------------|-----------|----------|----------|---|---|---|---|
| ORDER                | 11        | .620384  | 36       | .76 | n.s. |
| ORDER*ATD            | 11        | .116523  | 24       | .26 | n.s. |
| ORDER*VTD            | 11        | .156594  | 24       | .43 | n.s. |
| ORDER*PAY            | 22        | .579620  | 38       | .73 | n.s. |
| ORDER*ATD*VTD        | 11        | .095779  | 24       | .35 | n.s. |
| ORDER*ATD*PAY        | 22        | .227743  | 38       | .55 | n.s. |
| ORDER*VTD*PAY        | 22        | .392843  | 38       | .84 | n.s. |
| ORDER*ATD*VTD*PAY    | 22        | .238054  | 38       | .93 | n.s. |

**Note:**
ORDER = Order of conditions (1 through 12)
ATD = Auditory Task Difficulty (easy and difficult)
VTD = Visual Task Difficulty (easy and difficult)
PAY = Payoff Condition (high, low, or equal)
Table 10

Analysis of Variance Summary Table for the ORDER X ATD X VTD X PAYOFF Analysis on Visual Task Performance

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<th>ANOVA SS</th>
<th>df Error</th>
<th>F</th>
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</table>

Note: ORDER = Order of conditions (1 through 12)  
ATD = Auditory Task Difficulty (easy and difficult)  
VTD = Visual Task Difficulty (easy and difficult)  
PAY = Payoff Condition (high, low, or equal)
VITA AUCTORIS

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